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Chemistry teachers' pedagogical content knowledge in teaching hybridization

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ABSTRACT

Pedagogical content knowledge, PCK, a concept in teacher education requires additional focus and attention by pre-tertiary teachers to improve teaching and learning and learners' performance. The study adopted PCK model developed by Magnusson et al. (1999) to investigate senior high school (SHS) chemistry teachers PCK in teaching the concept of hybridization. The study adopted a qualitative approach using the case study design. Six chemistry teachers from six SHSs in the Upper West Region of Ghana were purposively sampled for the study. Semi-structured interviews, lesson plans analysis and observations were used as data collection instruments. Data was analyzed using content analysis. The findings reveal that most of the teachers have high knowledge of instructional strategies and knowledge of the science curriculum. In addition, it was revealed that many of the teachers have inadequate knowledge in their orientation towards science teaching, assessment of scientific knowledge, and in knowledge of students understanding of science. It was concluded that the teachers' PCK was inadequate since knowledge of instructional strategies and knowledge of curriculum alone does not define an effective science teacher. The study recommended that in-service professional training in PCK should be organized for teachers to improve their classroom practices.

Keywords: case study, hybridization, pedagogical content knowledge, qualitative approach, substantive knowledge, syntactic knowledge

INTRODUCTION

Hybridization is one of the important concepts in atomic orbital chemistry (Nakiboglu, 2003), chemical and molecular bonding (Calis, 2018; Koomson et al., 2020). The chemistry curriculum of Ministry of Education (MoE) of Ghana specified that learners are expected to understand the concept of hybridization, formation of sigma and pi bonds, types and formation of hybrid orbitals, and shapes of molecular compounds (MoE, 2010).

However, in teaching and learning, the topic hybridization has been identified as one of the most abstract and difficult concept for classroom instruction (Abukari et al., 2022; Calis, 2018; Jian, 2014; Salah & Dumon, 2011). Research conducted have revealed that students have difficulties in learning the concept of hybridization by Abukari et al. (2022), Calis (2018), Hanson et al., (2012), Jian (2014), Koomson et al., (2020), Nakiboglu (2003), and Salah and Dumon (2011).

Some of the difficulties students experience in learning hybridization has been attributed to gaps in teacher knowledge in teacher training (Rollnick & Mavhunga, 2014). Some of these difficulties include teaching techniques and approaches (Sahin et al., 2016; Udogu et al., 2007) used by the teachers, as well as the teachers' content knowledge and assessment methods (Abell, 2007; Sakim, 2004) used by the teachers among others. These difficulties have also been found to have an impact on students' academic achievements (Hanson et al., 2012).

Pedagogical content knowledge (PCK), proposed by Shulman (1986), intimated that it is how the content of a concept is introduced by making use of instructional techniques such as analogies, diagrams, illustrations, examples, explanations, and demonstrations, thus, organizing the subject matter in a way that will motivate learners to understand (p. 8). These analogies, diagrams, illustrations, examples etc. when used effectively can promote students' understanding and improve academic achievement in the classroom (Shulman, 1986). He also added that PCK instills various knowledge domains, subject matter, instructional techniques, teaching and learning materials, students' needs, and evaluation methodologies, among other things, to help learners comprehend certain ideas (Shulman, 1987).

Teachers who understand how their students learn would use their PCK to help the students develop knowledge, acquire learning, reading, and listening skills, develop the habit of the mind and its positive attitude towards classroom instruction (Jacob et al., 2020). Teachers can devise an effective strategy for teaching if they have adequate content knowledge and understand how their students learn (Tsafe, 2013). A teacher who has adequate content and pedagogical knowledge of the subject and topic, teaches effectively during classroom instruction (Bozkurt & Kaya, 2008; Jang, 2011; Nuangchalerm, 2012). Shulman (1987) added that the understanding of how the content is organized and taught promotes meaningful learning. PCK therefore includes all the instructional materials and strategies employed by teachers to make the concept easy or difficult to learn (Jacob et al., 2020; Shulman, 1986)). Koehler and Mishra (2009) opined that teachers need to understand the learning theories (cognitive, developmental, and social) and their influence in the classroom to be able to demonstrate good PCK.

Many researchers have established that teachers' PCK influences how their teaching is carried out in the classroom (Karisan et al., 2013; Koehler & Mishra, 2009; Pihie & Sipon, 2013; Shulman, 1987). Mensah (2013) posited that the efficiency of teaching is highly enriched by the teacher's pedagogy and content knowledge and therefore combining the content knowledge of teachers and their instructional methods will engender a multidimensional and dynamic classroom context of a PCK, which can enhance students' academic achievement.

In order to enhance and help improve students' academic performance in hybridization and achievement in chemistry in general, it is important to understand the PCK of chemistry teachers on hybridization. Understanding the PCK of chemistry teachers in concepts such as hybridization is key in unraveling reasons for students' poor performance and achievement in chemistry. This should lead to the first step to designing a necessary and effective intervention initiative to address the issues of students' poor achievement in chemistry. This study therefore explores the PCK of chemistry teachers in teaching the concept of hybridization.

Problem Statement

Research revealed that inadequate PCK is an area in teacher education that requires additional focus due to lack of depth of subject matter and PCK by teachers necessary to improve learners' performance according to Boerst (2003), Dooren et al. (2005), Halim and Meerah (2002), and van Driel et al. (1998). The teacher factors that bothered on PCK such as poor content knowledge, poor instructional skills, poor assessment skills, and poor teaching methods were the most critical factors attributable to learners' poor performance in hybridization (WAEC, 2008, 2012, 2017, 2019). Studies also found that other factors, which appear to have bearing on PCK, which affects teaching are insufficient textual resources, inadequate pedagogical techniques and teacher competence and teacher's poor knowledge of instructional material for teaching specific science topics (Braimoh & Okedegi, 2001).

Several studies have been conducted on PCK of chemistry teachers on topics like electrochemistry (Aydin et al., 2014); redox reactions (Goes et al., 2020; Rollnick & Mavhunga, 2014), phase transition of matter (Ozden, 2008; Usak et al., 2011), amount of substance and chemical equilibrium (Rollnick et al., 2008), chemical bonding (Vladušić et al., 2020). Other studies have reported on teachers PCK in other subjects like mathematics, physics and biology. However, few studies have been done on chemistry teachers' PCK on hybridization.

Research Questions

The study sought to answer the question: What is the PCK of chemistry teachers in hybridization?

LITERATURE REVIEW

Theoretical Framework

The study drew on Shulman's (1986) theory on PCK, which formed the basis for a knowledge of teachers on their subject matter and its impact in promoting effective teaching and learning. Shulman (1986) viewed PCK as how the content of a concept is introduced by making use of instructional techniques such as analogies, diagrams, illustrations, examples, explanations, and demonstrations, and organizing the subject matter in a way that will motivate learners to understand'' (p. 8), the concepts taught. In addition, knowledge of representation of specific information and instructional techniques, comprehension of learning challenges, and students' ideas of specific content, are crucial factors in Shulman's (1986) theory of PCK. PCK is a distinct body of knowledge for classroom instruction, according to Shulman (1986), that represents the combination of subject matter and teaching methodology into an understanding of how specific content, difficulties, or issues are planned, represented, and modified to the diverse interests and abilities of learners, and presented for instruction.

It is important to appreciate how the learning environment is organized as a teacher in order to facilitate students' grasp of concepts of specific topics and contribute to their intellectual understanding and development. The ability to demonstrate and make the teaching of a subject simple to understand and to learn is the PCK (Shulman, 1986). PCK assists teachers in developing competency in providing the content in alternative interactive knowledge, and adaptive reasoning of the content to students/learners in classroom instruction (Jacob et al., 2020). It is also the combination of understanding the content, pedagogical methodologies, and learner knowledge to create an effective classroom environment (Pihie & Sipon, 2013). Again, PCK is an important information required by teachers to plan the lesson, select appropriate teaching methods, select instructional materials to address the needs of the students during the teaching and learning process (Jacob et al., 2020).

Conceptual Framework for the Study

Components of pedagogical content knowledge

The study adopted the conceptual framework PCK model of Magnusson et al. (1999). PCK model by Magnusson et al. (1999) outlined the key and important components of teachers' PCK that influence how chemistry teachers teach the concept of hybridization in this study. The model developed by Magnusson et al. (1999) is considered as extremely reliable model to analyze PCK of chemistry teachers (Boesdorfer, 2012). The model of Magnusson et al. (1999) demonstrates that numerous factors can be utilized to categorize the concept of PCK in the case of this study. Thus, knowledge of the subject matter (including substantive and syntactic knowledge), knowledge of pedagogy and educational goals, knowledge of the classroom, and knowledge of content, including knowledge of particular learner and school characteristics, are the variables in the model. Halim and Meerah (2002) identified ways of representing particular ideas or concepts that will make learning easier to help interpret PCK. "Orientations towards teaching science," "knowledge of science curriculum," "knowledge of students' comprehension of science," "knowledge of instructional techniques," and "knowledge of assessment for science" are among the PCK components in Magnusson et al. (1999) model for teaching science. The elements of PCK for teaching the chemical concept of hybridization are shown in **Figure 1**.

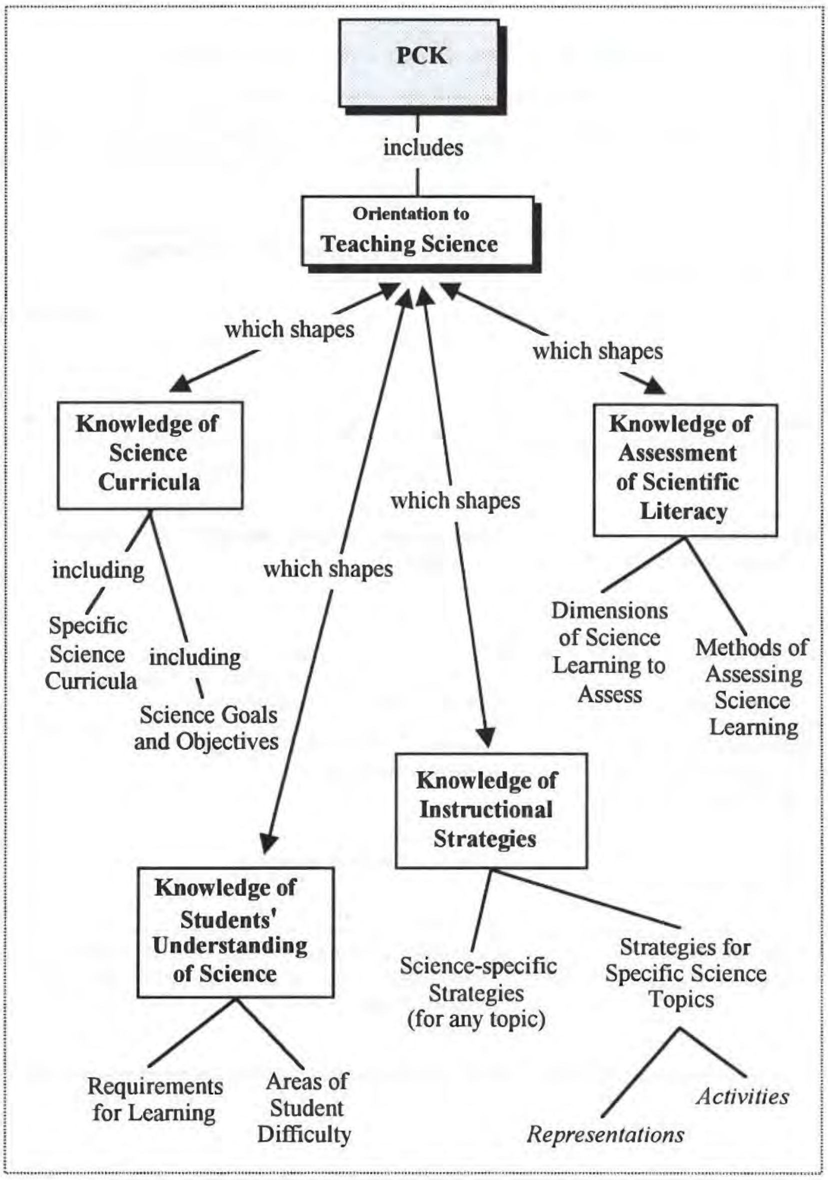

Figure 1. PCK model for teaching science (Adapted from Magnusson et al., 1999, p. 99)

Chemistry teachers receive orientations for teaching the subject and the content as part of their training in the university and other higher institutions. Understanding the purposes and objectives for teaching science at a specific grade level is part of the teachers' approach towards teaching science. According to Nargund-Joshi and Liu (2013), teachers' preferences for teaching science may be thought of as either filters or amplifiers that influence how they behave in the classroom as a whole. To start changing the way teachers behave in the classroom, it is important to examine their views on how science is taught and learned. The orientations that teachers receive as part of their training influences their knowledge of chemistry curriculum, students learning, teaching techniques and approaches for chemistry instruction and assessment techniques for assessing learners learning in the chemistry classroom.

Knowledge of chemistry curriculum includes the teacher's knowledge of the aims and objectives for teaching chemistry and knowledge of curricular materials suitable for teaching chemistry. Every chemistry teacher should have a knowledge and understanding about the chemistry curriculum. This includes knowledge of the goals and objectives for teaching the subject chemistry and the topic hybridization, knowledge about the programs, national policy document on science education and the relevant teaching and learning materials for teaching the topic hybridization. This means, the general goals of the chemistry curriculum, various activities and materials used to achieve these goals constitute curriculum knowledge of chemistry teachers. In addition, the knowledge a teacher possesses in a certain subject/topic, according to Parrotte (2016), is his/her content knowledge. For instance, a chemistry teachers understanding of the concept of hybridization as presented in the curriculum is the subject-matter knowledge in hybridization. Hence, a teacher understanding the various programs and curricula options including instructional resources for effective teaching and learning constitute content knowledge. Therefore, one of the components of PCK that is easily assessed, according to Parrotte (2016), is the content knowledge.

Knowledge of students learning in chemistry includes teachers knowing the requirements for teaching chemistry as well as knowing the areas of students' learning difficulties. Knowledge of students understanding according to Ijeh (2012) is how the learners comprehend what is imparted during instructions. This suggests how learners see and comprehend the topic introduced to them by the teacher in the classroom. This component of PCK creates awareness for teachers on how their students learn and understand the content taught. Also, the requirement for learning specific science concepts and areas of science that students find difficult to learn are the two categories of knowledge for students learning. For knowledge of requirement for learning according to Magnusson et al. (1999) is the knowledge and beliefs about prerequisite knowledge for learning specific knowledge as well as their understanding of scientific concepts. Thus, the age, grade level and the different learning styles of students should be understood by teachers to promote meaningful leaning. In addition, the aspect of science that students find difficult to learn is the teacher's awareness about the topics that learners find challenging to learn and the root causes of such challenges. Thus, according to Magnusson et al. (1999), students find it challenging to understand abstract concepts (like hybridization) that cannot be related to their prior knowledge. To be effective, teachers must be aware of students' various learning capacities and styles and respond appropriately. Teachers understanding of the difficulties students experience and how they struggle to learn a concept (like hybridization) is very important during instructions. Because learning is based on what happens in the classroom, not only what students do, but also the learning environment, knowledge of students' perceptions is seen as one of the crucial aspects of teacher knowledge. This was confirmed by Halim et al. (2011) who revealed that PCK of teachers has a favorable impact on students' conceptual understanding of cell respiration.

Knowledge of instructional strategies for teaching chemistry includes teachers' knowledge of subject specific instructional methods and topics, specific instructional techniques. In addition, chemistry teachers' knowledge about teaching methods includes their understanding and ideas about teaching strategies/methods or specific activities to enhance conceptual understanding among students during instruction. Knowledge of evaluation in chemistry involves the teachers' understanding of the categories of learning they employ to assess and the knowledge of the techniques of assessment in chemistry. Hence, teachers need to have an understanding about the different assessment techniques they employ during instruction to promote meaningful learning.

METHODOLOGY

General Background

Qualitative approach and a case study design was adopted for the study. Qualitative approach enabled the research to gather, analyze, and interpret qualitative data for the study (Creswell, 2014). The philosophy that underpinned the study is the interpretive paradigm.

Sample and Sampling Procedure

The study targeted senior high school (SHS) chemistry teachers in Upper West Region, Ghana. Purposive sampling technique was employed to sample six SHS chemistry teachers from six SHSs in Upper West Region, Ghana. The purposive sampling procedure was used because some of the SHSs do not offer chemistry as an elective subject in their program of instruction. These schools were also among poorly performing schools in the area.

Research Instruments

Observation schedules and semi-structured interviews were used as data collection instruments.

Observation

The observation schedule consisted of five components on a five-point Likert scale, from "poor" (1) to "excellent" (5). The components are knowledge of instructional strategies, knowledge of assessment of science, knowledge of science curriculum, knowledge of students understanding of science and orientation towards science teaching. The scores of each component were computed out of a total score of 100.

The mean component scores for each teacher were obtained by summing up the scores of all the items in sub-scale/component and dividing by the number of items. Summated scores were obtained by multiplying the mean scores of each component by the number of items in the component.

Percentage component scores were obtained by dividing summated scores by the maximum component scores and multiplied by 100. This was computed for each teacher. The number of items on each component and the minimum and maximum summated scores are shown in **Table 1**.

Table 1. Number of items on PCK component measured

PCK component	Number of items	Minimum score	Maximum score
Knowledge of instructional strategies	9	9	45
Knowledge of assessment of science	4	4	20
knowledge of science curriculum	11	11	55
Knowledge of students understanding of science	4	4	20
Orientation towards science teaching	2	2	10

Semi-structured interview

For triangulation purposes, the observation was employed together with the interviews to help the researcher confirm the responses. To obtain more detailed information on teachers' PCK on the concept of hybridization, semi-structured interviews were conducted. The components of PCK by Magnusson et al. (1999) guided the construction of the interview protocol and included: orientations to teaching science, knowledge of the student's understanding of science, knowledge of science curricula, knowledge of instructional strategies, and knowledge of the assessment in science. The interview protocol was pilot tested and further fine-tuned.

Data Collection Procedure

Content of the topic hybridization from Ghana education service chemistry syllabus was used by the chemistry teachers to prepare a four-week lesson on the concept of hybridization. The students were taught by their teachers for the period of four weeks. The lessons were observed using the observation schedule.

The teachers were also interviewed before and after each lesson. The teachers taught the topic in the subsequent days and the lessons observed using the observation schedule. The interview was face to face and lasted between 45-60 minutes. The interview was recorded and transcribed verbatim.

Data Analysis

Content analysis was used to analyze 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. Content analysis entails turning a large set of raw data into useable evidence through data reduction methods (Hawkins, 2013). The data was coded and categorized into themes based on the component of PCK by Magnusson et al. (1999). The results were presented in tables and figures. Also, the responses of the chemistry teachers were analyzed for similarities and differences, to obtain information about the chemistry teachers' PCK on the concept of hybridization based on their teaching experience. The data from the classroom observation checklist was analyzed based on the pedagogical skills of the chemistry teachers.

RESULTS/FINDINGS

The results in **Table 2** revealed that majority of the chemistry teachers were males (83.3%) with only one female. Also, the ages of the teachers show that 50.0% of the teachers were between the ages of 25-30 years and the remaining above 30 years. All the six chemistry teachers sampled had a first degree (BSc. or BEd.) and a second degree (MSc.) as their highest academic qualification. Four teachers had an experience in teaching chemistry from one-five years, and the remaining two had taught chemistry for over five years.

Table 2. Demographic data of chemistry teachers

Variable	Number of teachers	Percentage (%)
Gender		
Male	5	83.3%
Female	1	16.7%
Age		
25-30 years	3	50.0%
31-35 years	2	33.3%
36 years & above	1	16.7%
Academic qualification		
Bachelor of science (BSc.)	3	50.0%
Bachelor of sducation (BEd.)	2	33.3%
Master of science (MSc.)	1	16.7%
Number of years teaching chemistry		
1-5 years	4	66.7%
6-10 years	2	33.3%

Table 3 shows the mean and standard deviation of teachers' PCK.

Table 3. Mean (M) & standard deviation (SD) of teachers PCK

PCK component	Teacher A		Teacher B		Teacher C		Teacher D		Teacher E		Teacher F	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Knowledge of instructional strategies	2.41	0.299	3.98	0.399	4.22	0.497	2.53	0.246	3.78	0.44	2.5	0.372
Knowledge of assessment of science	2.23	0.196	2.58	0.453	2.23	0.198	2.23	0.157	2.76	0.265	1.87	0.411
Knowledge of science curriculum	2.56	0.322	4.04	0.66	4.01	0.741	3.02	0.454	3.45	1.039	3.13	0.449
Knowledge of students understanding of science	2.05	0.782	3.75	1.33	2.08	0.319	2.91	0.582	2.5	0.389	2.08	0.302
Orientation towards science teaching	1.66	0.898	4.16	0.19	1.66	0.12	1.66	0.586	3.04	1.414	3.33	0.572

Research Question

PCK of chemistry teachers in hybridization as presented on **Figure 2**.

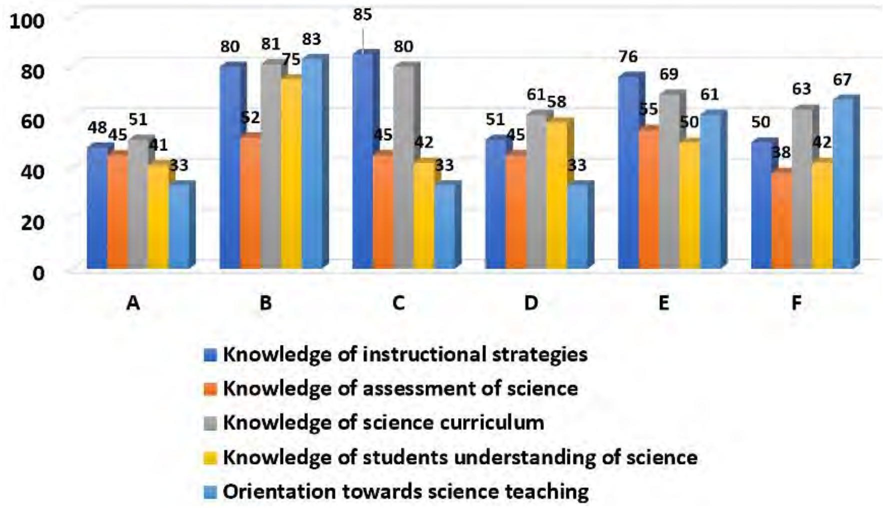

Figure 2. Teachers score on PCK components in teaching hybridization (Source: Authors' own elaboration)

Figure 2 showed the PCK component scores of chemistry teachers in teaching the concept of hybridization in chemistry. If a teacher scores above 60% on a component of the PCK, it shows the teacher has a good PCK while a component score of less than 60% indicates a poor/bad PCK.

It was revealed that teacher A had a PCK component score of 48% on the knowledge of instructional strategies, 45% on assessment knowledge, 51% on science curriculum knowledge, 41% on students understanding of science and 33% on orientation towards science. This implies that teacher A had a poor PCK in teaching the concept of hybridization with an average score of 43.6%.

It was also revealed that teacher B scored 80% on knowledge of instructional strategies, 52% on assessment of science knowledge, 81% on science curriculum knowledge, 75% on students understanding of science and 83% on orientation towards science teaching. This implies that teacher B had a high PCK in knowledge of instructional strategies, curriculum, students understanding of science and orientation towards science teaching. Hence, the teacher had a poor PCK on knowledge of assessment of science. Hence, teacher B had a high PCK in teaching the concept of hybridization with an average score of 74.2%.

It was found that teacher C scored 85% on knowledge of instructional strategies, 45% on knowledge of assessment of science, 80% on science curriculum knowledge, 42% on knowledge of students understanding of science and 33% on orientation towards science teaching. This implies that teacher C had a high PCK on knowledge of instructional strategies and curriculum, with a percentage score above 60%. However, the teacher had a poor PCK on assessment knowledge of science, students understanding of science and orientation towards teaching science. Hence, teacher C had a limited PCK in teaching the concept of hybridization with an average score of 57.0%.

The results also revealed that teacher D scored 51% on knowledge of instructional strategies, 45% on knowledge of assessment of science, 61% on knowledge of science curriculum, 58% on knowledge of students understanding of science and 33% on orientation towards science teaching. This implies that teacher D had a high PCK on knowledge of science curriculum with a percentage score above 60%. However, the teacher had a poor PCK on knowledge of instructional strategies, assessment of science, students understanding of science and orientation towards science teaching. Hence, teacher D had a poor PCK in teaching the concept of hybridization with an average score of 49.7%.

The results revealed that teacher E scored 76% on knowledge of instructional strategies, 55% on knowledge of assessment of science, 69% on knowledge of science curriculum, 50% on knowledge of students understanding of science and 61% on orientation towards science teaching. This implies that teacher E had a high PCK on knowledge of instructional strategies, curriculum and orientation towards science teaching. However, the teacher had a poor PCK on knowledge of assessment of science and students understanding of science. Hence, teacher D had a high PCK in teaching the concept of hybridization with an average score of 62.2%.

Again, the results also revealed that teacher F scored 50% on knowledge of instructional strategies, 38% on knowledge of assessment of science, 63% on knowledge of science curriculum, 42% on knowledge of students understanding of science and 67% on orientation towards science teaching. This implies that teacher D had a high PCK on knowledge of science curriculum and orientation towards science teaching. However, the teacher had a poor PCK on knowledge of instructional strategies, assessment of science and students understanding of science. Hence, teacher D had a poor PCK in teaching the concept of hybridization with an average score of 52%.

Therefore, with an average PCK score of 74.2% and 62.2%, teacher B and teacher E had high PCK in teaching the concept of hybridization while teacher A (43.6%) had the lowest.

Figure 3 showed that many of the teachers scored high on knowledge of instructional strategies and science curriculum. Again, it was revealed that many of the teachers scored low in their orientation towards science teaching, assessment knowledge and students understanding of science. Thus, it is revealed that the teachers have poor PCK since knowledge of instructional strategies and curriculum alone does not define an effective science teacher.

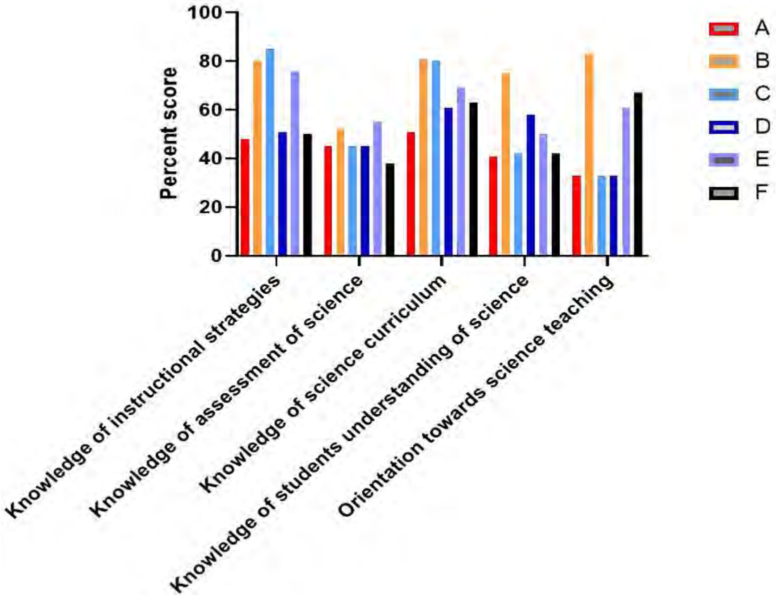

Figure 3. PCK component scores (Source: Authors' own elaboration)

Analysis of Interview Data

Orientations towards science teaching

The teachers' knowledge and understanding of the purposes and objectives of teaching science at a certain grade level is described as the teachers' orientation towards teaching science. The orientations that teachers receive as part of their training influences their classroom practice. The interview questions 'how do you prepare to teach the topic hybridization and what conceptual issues are you going to employ to teach the concept hybridization?' were used to assess the knowledge of chemistry teachers' orientations towards science teaching.

Preparing to teach the topic hybridization

Responses to the question revealed that teachers do not seem to understand how they prepare to teach the topic. The findings above revealed that three out of the six teachers (teacher B, teacher C, and teacher E) representing 50% prepare adequately before lesson delivery. This showed that some of the chemistry teachers clearly set the learning objectives in their lesson plans as a guide in teaching. Some of the participants responses when asked how they prepare to teach the concept of hybridization.

> Teacher B: I prepare to teach the topic by writing down the lesson, plan the lesson, write down and explain key words. Prior to teaching the topic hybridization, I try to understand and explain the terms atomic orbital, ground state and excited state electron configuration among others.

> Teacher C: I always read about the topic and prepare TLMs for the lesson as part of my preparation to teach the topic hybridization. This helps me to prepare a lesson plan on the topic.

> Teacher E: I prepare lesson plan using the chemistry syllabus by gathering relevant information and materials about hybridization necessary for effective delivery in the classroom.

The remaining three teachers (teacher A, teacher D, and teacher F) representing 50% read, revised, gathered appropriate teaching and learning resources (TLRs), prepared charts and modules before teaching the concept of hybridization.

> Teacher A: As I prepare to teach the topic hybridization, I ask the following questions: what hybridization is, types of hybridization and shapes of hybridization. These questions help me to teach the topic very well for students to understand.

> Teacher D: I always prepare to teach the topic hybridization through revision of the topic as well as gathering of teaching and learning materials.

> Teacher F: as part of my preparation to teach the topic hybridization I always gather TLMs, prepare charts and modules on hybridization to help me teach the concept.

This finding agreed with the findings of Olteanu (2017) who added that the lesson objectives should have a strong connection in the lesson plan. This implies that the lesson objectives and goals clearly align with content of the topic hybridization, teaching strategies to achieve the objects and the context of the lesson. Hence, chemistry teachers must have knowledge of orientation toward teaching to make sure that the hybridization content they choose for their lesson plans is delivered at a level, where students can grasp it and so improve their performance.

Conceptual issues employed by teachers to introduce the concept of hybridization

Also, 50% (three out of six) of the teachers could not explain the conceptual issues a teacher must comprehend in other to teach the concept of hybridization. Thus, the teachers had a limited knowledge in the introduction of the topic when the teachers were quizzed on the conceptual issues they employ to introduce the concept hybridization to their students, they responded, as follows:

> Teacher C: I always explain the chemical phenomenon through the use of molecular level of presentation of the topic hybridization.

> Teacher D: the conceptual issues I usually employ to introduce the concept hybridization is the concept of chemical bonding.

> Teacher E: I discuss with students the importance of bonding and why overlapping of atomic orbitals is necessary for their understanding.

However, some of the teachers link the student's relevant previous knowledge (RPK) in teaching hybridization, showing videos on hybridization, atomic orbital theory and bond formation. Hence, 50% of the teachers had this to say about the conceptual issues a teacher needs to understand to teach the concept of hybridization.

> Teacher B: to introduce the topic to the students, I always try to link their RPK to the topic. For instance, taking rice and beans as a delicacy in students' common market, the shape of the beans as s-orbital and the shape of rice as p-orbital. This therefore helps the students to link what they already know to the concept hybridization and, hence facilitating their understanding.

> Teacher A: I use atomic orbital theory and bond formation to help introduce the concept hybridization to my students.

> Teacher F: I introduce the lesson by showing videos on hybridization to my students as part of my introduction when teaching the concept of hybridization.

Knowledge of science curriculum

The lesson plans prepared by the teachers' and some questions in the interview helped to assess the curriculum knowledge of the chemistry teacher's in teaching the concept of hybridization. It was observed in the lesson plans that teachers stated simple, measurable, achievable, relevant and timebound learning objectives in teaching the concept of hybridization. Some of the teachers wrote four lesson notes for each of the content areas of the topic while others developed only one lesson notes for the topic. Other teachers also stated the lesson notes as presented in the chemistry syllabus.

Concept (s) students need to know before they learn the concept of hybridization

The curricula knowledge of chemistry teachers was revealed by their response to the interview question, what concept (s) would students need to know before they learn the concept of hybridization? Some of the concept's students need to know before they learn the concept of hybridization include, atomic orbital theory, chemical bonding, shapes of orbitals, and electron configuration of elements. Although some of the teachers could not give reasons why the concept hybridization is taught at the SHS 1 grade level, they were able to provide responses to the concepts students need to know before they are taught hybridization as they stated:

> Teacher A: students need to have an idea about atomic orbital theory and chemical bonding before learning hybridization.

> Teacher B: Students need the concept of atomic orbitals, their shapes s, p_x, p_y and p_z and d. And also, chemical bonding that is covalent bonding to be precise.

> Teacher C: students need an understanding in shapes of orbitals, electron configuration and chemical bonding specifically intermolecular bonding to learn and understand hybridization.

Teacher D: they will need to be taught chemical bonding, shapes of orbitals and electron configuration of elements to help them learn and understand the concept hybridization.

Teacher E: students need the concept of chemical bonding to learn hybridization.

Teacher F: the students need to know the concept of chemical bonding and electrons in atoms to understand hybridization.

Also, all the chemistry teachers explained that students need to understand some concepts like atomic orbital theory, chemical bonding, shapes of orbitals and electron configuration of elements before they learn the concept of hybridization. These findings agreed with the work of Calis (2018) and Wu et al. (2001) who opined that students should have a solid understanding of chemical bonding and atomic orbitals in order to comprehend the concept of hybridization. This was also confirmed in the lesson plans and classroom observations when teachers linked students' previous knowledge to these concepts. However, some of the chemistry teachers (two out of six) lacked knowledge on the reasons why students need to know the concept shapes of orbitals, electron configuration and covalent bonding before they are taught the concept of hybridization:

''Students need to know the concepts because it gives a clearer picture of how atomic orbitals are mixed to form stable orbitals'' (teacher A).

''For them to understand what hybridizing all is about and make the teaching quite easy'' (teacher E).

In response to a further question, chemistry teachers were requested to explain why students would need the concepts mentioned above to learn hybridization. Four teachers representing 66.7% of the participants revealed that students need to learn and understand some concepts like shapes of orbitals, electron configuration and chemical bonding to facilitate their understanding in the concept of hybridization. They argued that:

Teacher B: Since hybridization is about mixing of atomic orbitals, there is this kind of correlation between them. For better understanding and delivery in the classroom, these topics are taught before hybridization.

Teacher C: They would need the concepts because knowledge in chemical bonding will help students to easily identify bonds whether single, double or triple in molecules when dealing with hybridization. Also, the knowledge in electron configuration will help students identify orbitals easily.

Teacher D: Shapes of orbitals will help students to understand the shapes of s and p orbital. They should be able to write the electron configuration of elements like C, O, N, Be, B, etc. in the ground state and excited state. Chemical bonding is fundamental for understanding hybridization and helps students with some shapes of molecules like NH_3, H_2O, etc.

Teacher F: they will appreciate the concept of hybridization if they understand bonding and its mechanics.

From the discourse above four chemistry teachers representing 66.7% of the participants agreed that students need to know the concepts because it gives a clearer picture of how atomic orbitals are mixed to form stable orbitals. Also, students need to understand what hybridizing all is about and make the teaching quite easy. According to the chemistry syllabus (MoE, 2010), teachers should expose students to orbitals in order for them to comprehend the concept of hybridization.

Some of the participants revealed that they do not actually understand or have an idea about what the students need to know before they are taught the concept of hybridization for meaningful learning. However, one chemistry teacher representing 16.7% of the participants lacked knowledge on the reasons why it was important for students to understand the ideas; shapes of orbitals, electron configuration and covalent bonding before they are taught the concept of hybridization. He argued that:

Teacher A: for the concepts to help my students understand the concept, Hybridization requires the mixing of two or more atomic orbitals to form stable atomic orbitals and bonds.

The response above revealed that the teacher lacked curricular knowledge on why students need to be taught some concepts before they are taught the concept hybridization. On the other hand, 83.3% of the participants explained with reasons why the concepts atomic orbitals, shapes of orbitals, electron configuration and chemical bonding help students in understanding the concept of hybridization as they postulated that:

Teacher B: The concepts help in establishing linkage, transition of the concepts to the topic hybridization for easy and quick understanding.

Teacher C: this is because, students talk about bonding electrons in hybrid orbitals and the knowledge in chemical bonding will help them understand better. Electron groups repel each other as much as possible.

Teacher D: linking the concepts shapes of orbitals, electron configuration and chemical bonding together helps students to link the concept hybridization to their RPK to enhance their understanding. Also, bonding tells how atoms uses electrons to form bond between themselves.

> Teacher E: The knowledge acquired from covalent bonding and the Lewis electron dot method is so different, hence makes explanation much easier.

> Teacher F: the concept of bonding will help students understand electron configuration and valence electrons and hence mixing of orbitals thus hybridization.

Teaching and learning materials used to introduce and teach the topic hybridization

In addition, the teaching and learning materials chemistry teachers use in teaching the concept of hybridization can also reveal knowledge of teachers in the chemistry curriculum because it is related to teachers' ideas about relevant instructional materials in the curriculum for teaching the concept of hybridization. This implies that teachers were asked about the teaching and learning materials they use (or would chose) when teaching the content of hybridization. Chemistry teachers interviewed had ideas about different teaching and learning materials use for teaching hybridization but did not bring them to the classroom to teach the concept. Though some of the teachers improvised some of the materials for teaching the concept, others did not use any teaching and learning material at all in delivering their lessons.

Though most of the teachers mentioned some of these items in their lesson plan and interviews, they did not use them during classroom instruction. Teachers were interviewed on the TLMs they employed to teach the concept of hybridization. The question ‘‘ what teaching and learning materials would you use to introduce and teach the topic hybridization (pre-interview) was used to reveal the curricula knowledge of chemistry teachers in the use of TLMs in teaching the concept of hybridization. The chemistry teachers mentioned some of the materials they would use in teaching the concept like molecular models, carboards, cardboard cut-outs, balloons, chem-kits, pictures, however, none of the teachers mentioned the use of computer animations, games and videos. Example of their responses are seen in the excerpts below:

> Teacher A: I will use molecular models and cardboard. I will use this material because, it enhances teaching and learning of hybridization.

> Teacher E: Organic model kit and pictures because it will help students understand the topic better.

> Teacher F: Chem-kit and models … students will group play with chem-kit and models, and this will enhance their learning abilities.

> Teacher C: Cardboard showing a clear illustration of molecular structures and organic molecular orbital kits because it will help students in understanding the bond structures and how orbitals overlap to form bonds.

> Teacher D: I will use three-dimensional diagrams of carbon bonded to hydrogen or halogens and inflated balloon. It will help students to see the shapes in three-dimensional network by making it real for them.

> Teacher B: A cardboard cut-out, cardboard illustrations, pictures, etc. ... I will use these materials because it makes the teaching and learning more practical, motivating and self-explanatory to students.

Teaching and learning materials in teaching the concept of hybridization

After classroom instruction, the chemistry teachers were asked about the TLMs they used in teaching the concept of hybridization, which also gave an idea about their curricula knowledge. Though the chemistry teachers mentioned some of these materials in the pre-interview (before teaching), they still mentioned them in the post interview. The lesson observations revealed that though teachers mentioned some of the TLMs they used, they did not use these materials in their lesson. They stated, as follows:

> Teacher A: Cardboard, molecular models (atomic balls).

> Teacher C: Cardboard illustrations because students get to see the model of the structures of the atomic orbitals.

> Teacher E: Organic molecular model kit, picture.

> Teacher F: Chem-kit for illustrations, models/pictures from computers on hybridization, cardboard illustration of sp, sp^2, and sp^3 hybridized orbitals.

> Teacher B: Cardboard cut-out, cardboard illustrations, pictures and organic molecular model kit.

The chemistry teacher's curricular knowledge on TLMs was further revealed in the study when the teachers were asked about how the materials mentioned by the teachers help students to learn the concept of hybridization and the reasons for using those TLMs for teaching. Teachers' responses reveal that they are aware of the importance of the use of TLMs in teaching and how it influences understanding. Example of their responses are seen in the excerpts below:

> Teacher A: It enhances teaching and learning and hence makes the lesson very effective for students.

Teacher C: Cardboard illustrations because students get to see the model of most of the structures of the atomic orbitals. Yes, because my school does not have organic molecular model kits.

Teacher E: The organic molecular model kit and the picture I used gave the student a mental picture of the topic under discussion and also made them understand it better.

Teacher F: To make it more practical and easier to understand the topic.

Teacher B: It makes the teaching and learning of the concept hybridization to be more practical, motivating and self-explanatory to students rather than the theoretical presentation. It also motivates students to practice the shapes on their own from their classroom experiences.

Teacher D: This is because, it gives the students the opportunity to interact with content in a way, which allows them to comprehend more easily.

The usefulness of TLMs in helping students to learn the topic hybridization

Chemistry teachers' responses on the ways the TLMs mentioned are useful in helping students learn and understand the concept of hybridization reveal that five out of the six chemistry teachers could not relate the TLMs mentioned to how they will aid learners in understanding the various concepts in the topic. The teachers had this to say:

Teacher A: It gives a better interpretation of the concept.

Teacher C: It helps students to proceed towards concrete learning.

Teacher E: It gives them a mental picture of the molecules under discussion and also keeps or arouses their interest.

Teacher F: TLMs are useful because they make students or learners understand the concept easier.

Teacher D: They are used in demonstrating sigma bonds and pi bonds.

Though majority of the teachers could not relate the TLMs to students learning and understanding, only one teacher (teacher B) related the TLMs to students learning in his responses and he argued that:

When it comes to the formation of the hybrid orbitals, shapes and bond angle formation. Also, in the formation of pi and sigma bonds. For example, two rams in a fight locally is sigma bond formation and local women dancing using their buttocks/sides to knock each other sideways or laterally is pi bonds (teacher B).

Knowledge of students' understanding of science

Understanding how well students learn science allows teachers to better understand how that knowledge affects their instruction. It reveals the chemistry teacher's knowledge about students' misconceptions in learning the concept of hybridization. Chemistry teachers were interviewed about some of the learning difficulties their students experience in teaching and learning the concept of hybridization, how they identify those learning difficulties, and the interventions used to assist students with these challenges. Some of the responses from the teachers reveal that they do not actually understand the learning difficulties of their students in hybridization. Some of the responses can be attributed to the experience of the chemistry teacher in the classroom. Some of the teachers' responses to the questions on the learning challenges experienced by their students were specific to chemistry while other responses were general. Some of the experienced teachers could identify some of their students' learning challenges, while others could not. Example of their responses are seen in the excerpts below.

Learning difficulties experienced by students in chemistry

Teacher C: Students are facing difficulty in understanding chemistry concepts due to the abstract, unobservable and particulate basis of chemistry. This difficulty is magnified in chemistry learning due to the need for rapid transfer among the macroscopic, submicroscopic and symbolic levels or thought.

Teacher A: Students find it difficult to brainstorm; they lack good grammatical expressions; they do not put enough effort to learn the subject.

Teacher B: Students fear to ask questions and answer questions; students have the mentality that chemistry is a difficult subject; unavailability of equipment's and apparatus to give practical demonstrations on certain topics.

Other teachers gave these general responses on students learning difficulties in chemistry.

Teacher E: Students' inability to fully comprehend the English language.

Teacher F: Difficulty in understanding certain concepts in chemistry education.

Learning difficulties experienced by students in the topic hybridization

The chemistry teacher's knowledge of their students was further revealed when they were asked to mention some of the challenges their students experienced learning the content hybridization. Some of the chemistry teachers were able to give the specific learning challenges that their students encountered when learning the concept of hybridization, while other teachers could not give or were unaware of the learning challenges experienced by their students as observed in their scripts. Example of their responses are seen in the excerpts below:

> Teacher D: Balancing the electron capacities involved in the formation of the new set of hybrid orbitals. Mixing of atomic orbitals after their exciting electron configuration; identification of the hybridization of the central atoms of sp, sp^2, and $sp^{3,}$ etc.; the total electron capacity of the hybrid orbitals was a challenge to balance it; hybridization involving hydrocarbons i.e., C_2H_4, CH_4, $CHCl_3$, $C_2H_{2,}$ etc.

> Teacher A: Sketch of the shapes; lack of effort to practice/revise at home; brainstorming.

> Teacher E: Students want to see a real-life presentation of hybridization; inability to recognize shape; students had a difficulty in balancing the electron capacities involved in the formation of the new set of hybrid orbitals; mixing of atomic orbitals after their excited state electron configuration; identification of the central atoms of molecules with sp, sp^2, and sp^3hybrid orbitals.

> Teacher B: Drawing the orbital diagrams; to determine the hybridization of atoms in a given compound; writing the excited state electron configuration of C, B and Be; how sp^3, sp^2 and sp hybrid orbitals are formed; how sp^3, sp^2, and sp hybrid orbitals are formed especially how the unhybridized p-orbitals overlap to form the pi bonds in sp and sp^2 hybrid orbitals.

Some of the teachers' responses also reveal that some of the chemistry teachers were unable to recognize the learning challenges that their students were experiencing during the teaching and learning process, demonstrating their limited PCK in terms of student knowledge.

> Teacher C: Students have difficulty in learning hybridization because the sub-microscopic molecular structures of particles cannot be seen whereas the symbolic level is a way a substance is represented its molecular formula.

> Teacher F: Lack of understanding the concept of hybridization.

Identifying students learning difficulty in the topic hybridization

In addition, chemistry teachers were asked on how they identify the difficulties their students experience in learning the topic hybridization. Responses from the teachers' further reveal their deficiency in the knowledge of students. Example of their responses are seen in the excerpts below:

> Teacher A: I used students' responses from assignments, test, question and answers to identify students' difficulty in learning the concept hybridization.

> Teacher B: I am able to identify students' difficulty in the topic hybridization when I ask question in the classroom. The response given by the students give me an idea about the difficulty of the student in the concept.

> Teacher C: I use the assessment I conducted, that is giving exercises and assessing how students answer each question.

> Teacher D: I always identify students learning difficulties in hybridization by given students trial work as well as assignments.

> Teacher E: I always use oral and written exams to identify students learning difficulty in hybridization.

> Teacher F: I identify students learning difficulties through the pre and post intervention test applied to the students in hybridization.

Interventions used to address the learning difficulties of students in hybridization

Furthermore, to understand teachers' knowledge on students learning, the chemistry teachers were asked to explain the interventions they employ to address students learning difficulty in hybridization. Example of their responses are seen in the excerpts below:

> Teacher A: to address to students learning difficulties, I always organize tutorials for the whole class or individual tutorials for students with peculiar difficulties. Also, I give out more task for students to practice in groups.

> Teacher B: I always give further explanation and solve multiple questions on a concept after the topic to help address students learning difficulty in the topic. I also solve the exercises, tests and assignment questions with student by helping them understand how they should have answered a particular question with reason why I marked them wrong.

Teacher C: By revising or repeating the topic once more and given them a lot of assignments, solving more examples in class to have a wide range of understanding the topic.

Teacher D: I employ one on one interaction with students with difficulties in the topic and also given challenged students special attention during classroom instructions.

Teacher E: I organize remedial classes for the students to elaborate further on their weakness as an intervention to address their learning difficulty.

Teacher F: I address students' difficulty in the concept by using models, chem – kit and videos to teach the concept hybridization.

In the concept of hybridization, for instance, the topic is sequenced from understanding what hybridization is (definitions, importance, characteristics, and procedures), the types and formation of hybrid orbitals (sp, sp^2, and sp^3), sigma and pi bonds formation and the shapes of molecular compounds. In a teacher's response on how he makes the topic easy for students learning, he indicated that

"if you teach them how sigma and pi bonds are formed before treating hybridization students easily understand the topic."

Thus, the teacher understands his PCK and does not follow the sequence in the syllabus for meaningful learning.

Difficulty of the topic hybridization

To get more insight on teachers understanding on students learning, teachers' responses on what makes the topic hybridization difficult or easy to teach and understand reveal that they do not understand the topic they teach. Example of their responses are seen in the excerpts below:

Teacher A: Hybridization is not applied on isolated atoms; thus, it only occurs at the time of bond formation. So many students ask whether we are treating bonding again because hybridization itself is bonding.

Teacher B: What makes the topic hybridization difficult is how to let students appreciate that hybridization is mathematical combination, that is, when one s- orbital is mixed with three of the p-orbitals to get four equivalent sp^3hybrid orbitals, which are directed towards four corners of a regular tetrahedron with bond angle of 109.5^0 between any two adjacent sp^3 hybrid orbitals. Also, what makes it a bit easier is when you teach them how sigma and pi bonds are formed before treating hybridization, students understand better.

Teacher C: Due to the occurring on molecular level in many chemical phenomena because understanding of hybridization is based on assigning meaning to the unseen and intangible.

Teacher D: The topic is easy to teach because of the concept of bonding, which is linked directly to hybridization.

Teacher E: The availability of organic molecular model kit in teaching the topic hybridization makes it easy for students to understand. Students unfamiliar with some shapes makes them find it difficult to understand the concept.

Teacher F: Students find it difficult to understand the concept when taught theoretically and easy to assimilate when taught practically with models, pictures and videos.

Knowledge of instructional strategies

The knowledge that chemistry teachers have with respect to understanding the various teaching strategies promote meaningful learning among students in the classroom.

Teaching methodology employed by chemistry teachers to teach the topic hybridization

The question ''which teaching method would you use? Why would you use that method?'' revealed teachers' knowledge of instructional strategies for teaching. Some examples of teaching methods used by the teachers were demonstrations, discussions, brainstorming, group play, lecture method. None of the teachers used the group method to teach the concept of hybridization although a teacher mentioned group play, however, he could not explain what group play was when asked to explain. Example of teacher's responses on the teaching methods they employed in their lesson are seen in the excerpts below:

Teacher A: Teacher-centered approach.

Teacher C: Demonstration and discussion method with marker board illustrations.

Teacher E: Brainstorming.

Teacher F: Demonstration and group play.

Teacher B: Demonstration and discussion.

Teacher D: Brainstorming.

Although the chemistry teachers mentioned some of the methods of teaching the concept of hybridization, some could not give the reasons why they used the method they employed to teach the concept with respect to the syllabus. The response from teacher A who employed the ‘‘teacher-centered approach’’, he indicated that

> ‘‘the student knows nothing about hybridization, and they are supposed to receive knowledge from me and follow instructions with the goal of positive results’’ (teacher A).

This implies that the teacher has a problem with the knowledge of his instructional strategy in teaching the concept of hybridization.

In addition, some of the chemistry teachers did not give specific responses with respect to the instructional method used. For example, teacher E and teacher D mentioned that they employed brainstorming to teach the topic hybridization and indicated that

> I used it (brainstorming) because students had previous knowledge of bonding. It helped the students to understand because they were able to relate bonding and overlapping of atomic orbitals (teacher E).

> I use brainstorming because it is an effective method of obtaining information from students to ascertain their strength (teacher D).

This implies that the brainstorming method alone cannot be used to teach the abstract topic hybridization, which reveals the teacher’s deficient knowledge in instructional methods. The teacher’s classroom observation reveals that they adopted teacher illustrations, discussion and demonstration in teaching the concept of hybridization. This was also the same for teacher F who talked about employing demonstration and group play in teaching but rather used lecture method in teaching the concept of hybridization.

Furthermore, although some of the chemistry teachers had insufficient knowledge of instructional techniques in teaching the concept while others had a good knowledge about their instructional strategies in teaching the concept of hybridization. They had this to say about why they used the methods in teaching the concept of hybridization.

> Teacher C: Because of the hybrid orbitals and shapes of molecules, the demonstration, and discussion methods will help students understand the concept.

> Teacher E: I used it because students had previous knowledge of bonding. It helped the students to understand because they were able to relate bonding and overlapping of atomic orbitals.

> Teacher B: I employ demonstration and discussion to make the topic more practical, attractive, easy and understandable to students. Also, with this teaching method, students participate and pay more attention to the lesson because they see a presentation not a model or notation in hybridization but physically tangible items.

From the interview interactions, some of the teachers were aware of the requirements of the curriculum for how the concept of hybridization should be presented, but unfortunately, they did not adhere to them in their class. This could possibly cause learning difficulty in the concept of hybridization. Some of the chemistry teachers had knowledge about the instructional methods required to teach the concept of hybridization. but exhibits little understanding of what the instructional method captured in their lesson notes entails.

Knowledge of assessment for science

Classroom assessment as a component of teachers PCK when used effectively can help improve learners’ academic achievement. Majority of the chemistry teachers mentioned tests, exercises, and assignments but failed to mention oral questions, demonstrations, project work, and students’ illustrations on the marker board. Thus, oral questions and students’ illustrations on the marker board were used by some of the teachers during the lesson as observed by the researchers.

Assessing students on hybridization

The question “how did you assess your students on the topic hybridization?” revealed that some of the teachers lacked understanding in the knowledge of assessment in the concept of hybridization. Example of their responses are seen in the excerpts below:

> Teacher A: I used concept test, assignments and exercises.

> Teacher B: Class exercises and assignments.

> Teacher E: Through written test.

> Teacher F: Pre-intervention test and post-test was administered and marked. Scores used.

> Teacher C: The use of class exercise and assignments.

> Teacher D: Through assignments, quizzes and class test.

Using assessment to identify students learning difficulties in hybridization

The chemistry teachers were also asked about how they use classroom assessment to identify students learning difficulties in the concept of hybridization. Example of their responses are seen in the excerpts below:

> Teacher A: Drawing/sketching of the shapes of the hybrid orbitals became a challenge for some students.

> Teacher B: I use class exercises and assignments to monitor students understanding of lessons to see whether they have understood. I always add some key questions for them to answer. If they are not able to answer, means they have a challenge.

> Teacher C: It pushes instruction by stressing the critical thinking and reasoning of students.

> Teacher E: By throwing questions at them and assessing their feedback as the lesson progresses.

> Teacher F: Upon marking, I was able to identify their difficulties through their answers.

Using students' assessment to solve their learning difficulties in hybridization

If the assessment methods employed by the teacher are understood and effectively implemented, it can help teachers, students, and school authorities to use to solve students learning difficulties in the classroom. Based on this the researcher further probed the selected teachers on how they used the assessment methods mentioned to solve the learning challenges of students in hybridization. Example of their responses are seen in the excerpts below:

One of the teachers organized remedial classes to assist students to overcome their difficulty in the concepts. That is,

> "after assessing them, where they were unable to give an accurate answer, remedial class is organized to address that problem" (teacher E).

Another teacher attended to students individually to address their challenges in the concept of hybridization. Thus,

> "I attended to students individually to explain, where they fell short" (teacher F).

Other teachers also added that they assisted students in the questions they had difficulty in answering. They had this to say,

> "by assisting them in the area most of the students were not able to score in the exercise" (teacher C),

> "by identifying their weakness through questions that could not be answered properly" (teacher D).

A teacher (teacher A) could not tell how he uses assessment to help students overcome their challenges in leaning the concept of hybridization. Hence,

> "students were allowed to practice the sketching of the shape and to have another hands-on modelling by the molecular model" (teacher A).

Although the teachers gave different views about how they use assessment strategies to help students overcome their challenges in learning the concept of hybridization, they could not give detailed explanations about the strategies they employ in their classrooms, thus further revealing their limited knowledge in classroom assessment.

DISCUSSION OF THE RESULTS

Orientation Towards Science Teaching

The study findings reveal that chemistry teachers clearly stated the learning objectives of their lessons in their lesson plans. This finding agrees with the findings of Olteanu (2017) who added that the lesson objectives should have a strong connection in the lesson plan. This implies that the lesson objectives and goals clearly align with content of the topic hybridization, teaching strategies to achieve the objects and the context of the lesson. Hence, chemistry teachers must have knowledge of orientation toward teaching the concept of hybridization to ensure that the content of hybridization selected in their lesson plans are presented at the understanding of learners and improve their performance. The study also reveals that teachers read, revised, gathered appropriate TLRs, prepared charts and modules before teaching the concept of hybridization. Also, 50% (three out of six) of the teachers could not explain the conceptual issues a teacher must comprehend in order to teach the concept of hybridization. Hence, the teachers had a limited knowledge on the conceptual issues in teaching the concept of hybridization. However, some of the teachers believe that to introduce the lesson on the concept of hybridization, they link the student's RPK, showing videos on hybridization, atomic orbital theory and bond formation.

Knowledge of Science Curriculum

The research reveals that most of the chemistry teachers have knowledge about the chemistry curriculum including the general goals, objectives, techniques and resources used to achieve the goals. The chemistry teachers were asked to describe the purposes and goals of their teaching based on the interview questions. The interview questions according to Loughran et al. (2006) assist science teachers to understand their content knowledge and why it is important to teach the content.

Also, the study findings reveal that chemistry teachers had adequate knowledge and skills in preparing, planning and developing their lessons in the concept of hybridization. In addition, the study reveals that majority of the teachers explain that students need to understand some concepts like atomic orbital theory, chemical bonding, shapes of orbitals and electron configuration before they learn the concept of hybridization. These findings agree with the findings of Calis (2018) and Wu et al. (2001) who believe that to understand the concept of hybridization, students need to understand the concepts atomic orbitals and chemical bonding. This was also confirmed in the lesson plans and classroom observations when teachers linked students' previous knowledge to these concepts. However, some of the chemistry teachers (2 out of 6) lacked knowledge on the reasons why students need to know the concept shapes of orbitals, electron configuration and covalent bonding before they are taught the concept of hybridization. This is the response of the teachers:

> "students need to know the concepts because it gives a clearer picture of how atomic orbitals are mixed to form stable orbitals" (teacher A).

> "for them to understand what hybridizing all is about and make the teaching quite easy" (teacher E).

The responses of these two teachers reveal that they lacked the curricular knowledge on why students need to be taught some concepts before they are taught the concept hybridization. This implies that majority of the teachers gave reasons that they facilitate students learning and understanding. On how the concepts facilitate students understanding, majority of the teachers (five out of six) explained that the concepts atomic orbitals, shapes of orbitals, electron configuration and chemical bonding are concepts students need an idea about before they are taught the concept of hybridization in chemistry. This is confirmed by chemistry syllabus (MoE, 2010).

The classroom observations made by the researcher confirm that most of the teachers were comfortable with the content and had no difficulty in presenting it while others were not prepared thus fumbling around. That is, they were more comfortable with their content knowledge but struggled with how to apply their pedagogical skills to teaching the hybridization concept. The study results do not support the findings of Ji-Won (2006) and Kuchemann (2007) that the teachers they researched in their study had challenges with their subject matter. They concluded that teachers with difficulty in their content knowledge will have a difficulty in identifying students with learning challenges. Shulman (1986) argued that for meaningful learning among students, there is the need for teachers to integrate their pedagogy and subject-matter expertise in how they understand the topics, the difficulties associated with the topics by organizing, presenting, and adapting them to the diverse interest and needs of the students. This can help teachers in their delivery.

With the concept of hybridization, the concept becomes difficult for students to learn and understand if they do not understand previously taught concepts. Since learning is from known to unknown, simple to complex, RPK in a lesson is very important in helping teachers. Classroom observations revealed that majority of the students did not ask, or answer questions posed by their teachers on their RPK when introducing and teaching the lesson. The teachers on the other hand did not find out whether they understood the previous lesson or not, but rather continued with the next concept. This could contribute to learning difficulty experienced by students since most of the teachers treated students as passive recipients instead of making them active in the lesson. This was revealed in a response from a teacher who agreed to use the ''teacher-centered approach'' to teach and added that

> "the student knows nothing about hybridization, and they are supposed to receive knowledge from me and follow instructions with the goal of positive results."

How can a teacher with these ideas help students to understand the concept? There is the need for teachers to understand that students often have some preconceived ideas about a concept when they enter the classroom, and it is their responsibility to help them understand the new concepts by making them take part in classroom instructions as active participants. This was confirmed by Chinn (2002) in his study that students experiencing learning difficulty is affected by how the lessons are arranged and taught by the teacher from simple to complex.

The study reveals that majority of the chemistry teachers had limited knowledge of curriculum in terms of how they select and use instructional resources. This finding is confirmed by Halim and Meerah (2002) that chemistry teachers' inability to use teaching and learning materials to explain scientific concepts also created learning difficulties among the students. The findings are also supported by the study by Mthethwa-Kunene et al. (2015) that the biology teachers they studied used their PCK to teach the content of basic genetics in a consistent and organized manner. Also, some teachers reinforced the understanding of the students in the concept by employing contextual -base teaching, illustrations, and drawings, cooperative teaching, and analogies while others used teaching and learning materials and inquiry-based learning. Classroom instruction should be supplemented with TLRs, according to the study.

The concept of hybridization is considered to be abstract and should be taught practically using ICT based or no ICT based TLRs such as computer simulation and computerized modeling software (Koomson et al., 2020), visual models (Essah & Emmanuel, 2019), and problem game learning (Ameyaw & Sarpong, 2015), balloons, videos among others as mentioned by the teachers. This according to Ajayi and Ogbeba (2017) would help students to understand the concept better. There is therefore the need for curriculum planners and developers to develop and recommend instructional materials that will motivate and enhance students understanding of abstract concept like hybridization.

Knowledge of Instructional Strategies

Knowledge of teaching techniques are the methods that chemistry teachers employ in the classroom in describing, demonstrating and presenting the concepts of hybridization for meaningful learning, according to Sahin et al. (2016). Although Research in science education have recommended student centered teaching strategies for teaching (Holtman et al., 2018), teachers still employ the teacher -centered approaches to teach.

Chemistry teachers are introduced to various teaching methods during their professional training as teachers and are aware of the aims and goals of the chemistry curriculum, which guides teachers to teach to increase students' conceptual understanding. Invariably, some of the SHS chemistry teachers employed the student-centered teaching approach (Holtman et al., 2018) in teaching SHS students, which resonates with teaching methods advocated in the chemistry syllabus. With hybridization being an abstract concept, the best teaching method to promote students' comprehension is by the use of the student – centered strategies.

Research findings reveal that knowledge of instructional strategies through teacher responses to interview and classroom observations did not conform to the teaching methods prescribed by the 2010 SHS chemistry syllabus for teaching the concept of hybridization (MoE, 2010). The recommended teaching methodology by the chemistry syllabus requires that teachers move away from behaviorist modes of instruction, such as the expository technique used in majority of the lessons observed by the researchers, and instead provide students with the option to participate actively in lessons. Some of the teaching methods used by the teachers were demonstrations, discussions, brainstorming, group play, lecture method. None of the teachers used the group method to teach the concept of hybridization.

From the interview interactions, some of the teachers were aware of the requirements of the curriculum for how the concept of hybridization should be presented, but unfortunately, they did not adhere to them in their class. This could possibly cause learning difficulty in the concept of hybridization. Some of the chemistry teachers had knowledge about the instructional methods required to teach the concept of hybridization. but exhibits little understanding of what the instructional method captured in their lesson notes entails.

Most of the teachers sampled used an expository method (such as lectures and "chalk and talk") during the lessons that were observed, which does not correspond with the student-centered teaching strategies that are recommended in the SHS chemistry syllabus (MoE, 2010) and the preferred teaching method mentioned. The teaching syllabus recommends that:

1. Brainstorm to come out with the meaning of the term hybridization.
2. Discuss the procedures involved in the hybridization of atomic orbitals.
3. Discuss how sp^3, sp^2, and sp hybrid atomic orbitals are formed and sketch the shape of molecules.
4. Discuss and sketch to show how sigma and pi bonds are formed in ethene and ethyne.
5. Discuss and sketch the shapes (linear, planar, and tetrahedral) form of some molecular compounds (MoE, 2010, p. 10).

Therefore, in teaching the topic hybridization, the methodology recommended by the syllabus is brainstorming, discussion and demonstrations. This tends to imply that there is no connection between the classroom teaching strategies used by SHS chemistry teachers as observed in the lessons compared to what they say and do in the classroom and what is specified in the MoE and GES chemistry curriculum. Therefore, teachers need to adopt student-centered teaching methods that would promote meaningful learning. The teaching methodology employed by a teacher can affect students not understanding the concept and hence contributing to students' difficulty in understanding a concept.

Several teaching methods have been recommended in literature to teach abstract concepts in chemistry such as hybridization to enhance students understanding and performance. The concept orbital hybridization is not only abstract in nature, but it is also a procedural knowledge, so a direct instruction strategy is needed so that students can easily master the concept. These techniques includes the use of computer simulation and computerized modeling software (Koomson et al., 2020), visual models (Essah & Emmanuel, 2019), and problem game learning (Ameyaw & Sarpong,2015), participatory teaching and learning approach (Adu-Gyamfi et al., 2020), computer simulation games (Bílek et al., 2018), conceptual change approach (Calik et al., 2009; Priede & Krumina, 2012), and cooperative learning approach (Avci et al., 2019), learning cycle (7E model) (Santi & Atun, 2020), mastery learning, advance organizers, inquiry-based learning and inductive teaching. The findings show that teachers are limited in employing some of these instructional strategies in teaching the abstract concept of hybridization. There is therefore the need for curriculum planners and developers to develop and recommend teaching strategies that will facilitate the teaching of the abstract concept such as hybridization to students.

The different instructional techniques teachers select and adopt during instruction improve students' understanding and performance. The findings reveal that only few teachers adopted different teaching strategies in their classrooms. This finding was confirmed by Sahin et al. (2016) and Udogu et al. (2007) who reveal that teachers generally lack the desired level of knowledge of teaching strategies. This is because, most teachers do not explore or practice new teaching strategies for teaching abstract concepts like hybridization to enable learners to participate actively in the classroom. This will help to address the needs of all the students in the classroom. Udogu et al. (2007) added that STM teachers observed seldom employed teaching techniques, and their teaching methods appeared to be didactic in nature, leaving students to memorize facts as their only method of learning. Sprenger (2003) in his study found out that different teaching methods employed by teachers help them to identify students' difficulties in learning a concept and adopt diverse learning strategies for students. The statement was also confirmed by Penso (2002) who argued that teaching methods can help a teacher to identify the learning difficulty of his student in the classroom and thus improve students' performance.

The results further reveal that the teaching experience of the chemistry teachers had an influence on the teaching method employed in the classroom. This is confirmed by van Driel et al. (2002) that teachers gain a growth in the knowledge of their teaching methods with instructional experience.

The findings on majority of chemistry teachers limited knowledge on the type of instructional methods employed in teaching the concept of hybridization confirms the findings of Halim and Meerah (2002). They reported that Malaysian Trainee Science teachers had limited PCK in promoting the conceptual understanding of their students in some selected physics concepts. They also added that teachers could not explain scientific ideas to their students due to the teaching methods they employed. Thus, the teachers lacked the knowledge required to help students understand the basic concepts in physics.

Knowledge of Students' Understanding of Science

The findings reveal that majority of the chemistry teachers had difficulty in identifying the learning difficulty of students in hybridization. This result does not support the findings of Ji-Won (2006) that prospective teachers though had a challenge in retaining their subject matter, they recognized students learning difficulties.

Many factors contribute to student learning difficulty, inadequate preparation by teachers, which leads to poor instructional techniques employed by science teachers (Okebukola, 1997); the inability of students to understand basic chemistry concepts; teachers not able to explain the sub-microscopic, macroscopic and symbolic learning (three-dimensional learning) (Taber, 2001); and the inability of learners to memorize basic concepts (Taber, 2001).

The research findings reveal that the poor teachers PCK contributed to a widespread learning difficulty of students in the concept of hybridization. The research results confirm with research reports that teachers limited PCK is the cause of students learning difficulties (Abell, 2007; Halim & Meerah, 2002; Ji-Won, 2006; Olfos et al.,2004; Tsafe, 2013: Udogu et al., 2007; Usak et al., 2011; Vistro-yu, 2000). Usak et al. (2011) study reveals that inadequate teaching and learning materials, misconceptions, and lack of information regarding teaching methods, assessment, evaluation, and students' needs can create learning difficulties in learners.

Also, Ji-Won (2006) confirmed that pre-service teachers had difficulty retaining their subject matter, they recognized students learning difficulties and were unable to assist them in overcoming the difficulties. This was due to their inability to address the difficulty that they had identified as a student problem, which could be a learning difficulty experienced by the students. Penso (2002) suggested that teachers understand the importance of their PCK in revealing their students' learning difficulties and assisting them to reduce them.

Halim et al. (2011) believe that the teachers' PCK influences learners' conceptual understanding of a concept. Abell (2007) in his study believes that science teacher lacks critical PCK like knowledge of students' learning chemistry and how they are evaluated. This can be a difficulty that affects classroom instructions. These assertions by Abell (2007) were observed from teachers' responses in the interviews and classroom observations. Also, when a teacher is deficient in one of the components of his PCK, it can have an effect on the other components since they all work together.

Knowledge of Assessment for Science

Assessment methods employed by teachers in the classroom can assist them measure students understanding and academic performance. They include oral questions, teachers calling students to answer questions on the board, classroom observation by teachers, scoring and grading exercises, tests and assignments, the type of questions asked in class, students who have problems reporting to the teacher, reading chief examiners reports and research publications on the topic. The findings reveal that majority of chemistry teachers interviewed indicated that they use tests and exercises to identify their student's difficulty in a lesson. The responses by teachers on using tests and exercises agree with the results of Jordan et al. (2005) who added that teachers are able to identify any type of difficulty their students experience during scoring and grading of tests, exercises, and assignments.

The study also reveals that chemistry teachers lacked knowledge in assessment based on their responses. This according to Abell (2007) revealed that science teachers' lack of awareness of critical PCK, such as students' science ideas and evaluation knowledge could be a stumbling block to better teaching and learning processes. In addition, Sakim (2004), when a chemistry teacher is deficient in teachers' knowledge of assessment, it may affect their assessment practices or procedures and students' achievement as well in the topic. This implies that when a teacher is deficient in any of the components of PCK, it can have a negative impact on the teacher's classroom practice (Sakim, 2004). For example, how a chemistry teacher evaluates his students in the classroom is one of the components of his PCK and provides critical responses to teachers about their teaching methods, instructional materials used, and students' learning difficulties and achievement.

CONCLUSIONS AND RECOMMENDATIONS

The study investigated PCK of chemistry teachers in teaching the concept of hybridization in chemistry in Ghana using the Magnuson et al. (1999) PCK model. The study has revealed that most of the chemistry teachers are deficient in some aspect of their PCK in the knowledge of students understanding, knowledge of curriculum, knowledge of instructional strategies and knowledge of assessment for science. Hence, when a teacher is deficient in any of the components of PCK, it can have a negative impact on the teacher's classroom practice (Sakim, 2004). For example, how a chemistry teacher evaluates his students in the classroom is one of the components of his PCK and provides critical responses to teachers about their teaching methods, teaching and learning materials used, and students' learning difficulties and achievement.

Also, most of the teachers scored high on knowledge of instructional strategies and knowledge of science curriculum. In addition, it was revealed that many of the teachers scored low in their orientation towards science teaching, knowledge of assessment and knowledge of students understanding of science. Thus, it can be concluded that the teachers have poor PCK in teaching the concept of hybridization since knowledge of instructional strategies and knowledge of curriculum alone does not define an effective science teacher.

The study reveals that some of the teachers prepare adequately before lesson delivery while others read, revise, prepare charts, models and gather appropriate teaching and learning materials before teaching the concept of hybridization. This showed that some of the chemistry teachers clearly set the learning objectives in their lessons plans as a guide in teaching. Also, some of the teachers could not explain the conceptual issues a teacher needs to understand to teach the concept of hybridization. However, some of the teachers believe that to introduce the lesson on the concept of hybridization, they link the student's RPK, showing videos on hybridization, atomic orbital theory and bond formation. This implies that some teachers had a limited knowledge in the introduction of the topic.

The results also revealed that the experience of the chemistry teacher with respect to the number of years of teaching influence their lesson planning and delivery. Hence, majority of chemistry teachers had adequate knowledge and skills in preparing, planning and developing their lessons in the concept of hybridization. Also, all the chemistry teachers explained that students need to understand some concepts like atomic orbital theory, chemical bonding, shapes of orbitals and electron configuration of elements before they learn the concept of hybridization to facilitate their understanding. Majority of chemistry teachers agreed that students need to know the concepts because it gives a clearer picture of how atomic orbitals are mixed to form stable orbitals. The chemistry teachers mentioned some of the materials they would use in teaching the concept like molecular models, carboard illustrations, cardboard cut-outs, balloons, chem-kits, pictures, however, none of the teachers mentioned the use of computer animations, games and videos. Teachers' responses also reveal that they are aware of the importance of the use of TLMs in teaching and how it influences understanding. Majority of the chemistry teachers could not relate the TLMs mentioned to how they will help the students to understand the various concepts in the topic.

Majority of the chemistry teachers were able to give the specific learning difficulties experienced by their students in learning the concept of hybridization while other teachers could not give or were unaware of the learning challenges experienced by their students as observed in their scripts. Majority of teachers were deficient in the knowledge of how they identify students' difficulties. Majority of the teachers were able to explain the interventions they employ to address students learning difficulty in hybridization. Majority of teachers do not understand whether the topic they taught was easy or difficult to students to learn.

Some of the teaching methods used by the teachers were demonstrations, discussions, brainstorming, group play, lecture method. Also, some teachers could not explain the reasons why they used the method they employed to teach the concept with respect to the syllabus. In addition, some of the chemistry teachers had insufficient knowledge of instructional strategies in teaching the concept while others had a good knowledge about their instructional strategies in teaching the concept of hybridization. Some of the chemistry teachers had knowledge about the instructional methods required to teach the concept of hybridization. but seems to have little knowledge about what the teaching method captured in their lesson notes entails.

Some of the teachers lacked understanding in the knowledge of assessment on how they assess their students, majority of teachers could not give detailed explanations about the strategies they employ in their classrooms, thus further revealing their limited knowledge in classroom assessment.

It is therefore recommended that; teachers should prepare adequately for their lessons before entering the classroom. Also, there is the need for teachers to use multimedia instruction (computer simulations) to assist students in mastering the abstract concept of hybridization in chemistry since none of the teachers used any IT based media in their lessons. In addition, the Ghana Education Service need to strengthen teacher professional development programs for chemistry teachers on novel and appropriate pedagogical skills in teaching methods, teaching and learning materials development and usage and assessment strategies in teaching the concept of hybridization and other abstract concepts in chemistry. This will increase the confidence of teachers in the classroom and improve their performance.

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