International Education and Culture Studies
ISSN 2766-6778
Vol. 4, No. 1, 2024
Published by STSL Press

Original Paper

Teacher General Pedagogy and Subject Matter Knowledge for Teaching Qualitative Analysis Concepts to Chemistry Students

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Abstract

Qualitative analysis of species in solutions, is an important concept in analytical chemistry that employs the use of instruments to separate, identify, determine, and distinguish both organic and inorganic substances in a sample of solution. However, qualitative analysis (QA) has remained a difficult concept for chemistry students to learn and understand. This study, therefore, explored how chemistry teachers used their general pedagogy and subject matter knowledge to teach students QA in the senior high schools. To achieve this purpose, the study made use of the qualitative research approaches. That is, 10 teachers involved in the study were selected through convenience and purposive sampling techniques. Interviews, observations, and field notes were the main instruments used to collect data from the 10 teachers. A total of 11 weeks were used in the processes of data collection, data sorting, coding, and visualizing using Nvivo software. The findings of the study showed that teachers did not see the concepts they teach under QA as difficult. However, what made the concepts difficult to teach was the kind of instructional strategies employed by teachers in teaching and the lack of the needed teaching experience from novice teachers. The study, therefore, recommended to teachers, especially novice teachers to require tutoring from experienced teachers to guide them on how to teach QA, employing a variety of instructional approaches, such as demonstration, individual-based active learning, and cooperative learning approaches in teaching QA to students.

Keywords: Chemistry qualitative analysis, content, context, pedagogy, teachers

Introduction

Chemistry has been considered the central science among the sciences because of the vital role it has played in both living and non-living things (Brown et al., 1994). Its link with other pure sciences and applied sciences has created numerous fields of study, such as biochemistry, chemical engineering, medicine, geochemistry, agro-chemistry, and environmental chemistry (Salman et al., 2011). Practically, the daily life of humans centers around the chemical choices we make with food, air, clothing, cosmetics, fuel, medicine, home, and family members (Nbina & Viko, 2010).

Chemistry being one of the important constituents of natural science has many dimensions to its learning in schools and colleges. For instance, analytical chemistry is one of the dimensions of chemistry that deals with methods of identification, separation, and determination of species (atoms, ions, and molecules) in a sample. Analytical chemistry could be broken down into two general areas of analysis (qualitative analysis [QA] and quantitative analysis), and each one of these two types could be either classical or instrumental. Qualitative instrumental analysis has employed the use of instruments to separate and distinguish substances (organic or inorganic) in a sample. Examples are Gas Chromatography–Mass Spectrometry (GC – MS), High-Performance Liquid Chromatography – Mass Spectrometry (HPLC – MS), Infrared Spectra (IR), and Induced Coupled Plasma – Mass Spectrometry (ICP–MS) or ICP – AES (Atomic Emission Spectrometry) (Svehla, 2008). Chemical analysis [a concept in analytical chemistry] is one of the important chemistry concepts that help students understand and appreciate chemical reactions that occur in solutions (Anim-Eduful & Adu-Gyamfi, 2023). Students with deep conceptual understanding in chemical analysis help improve their scientific understanding (Anim-Eduful & Adu-Gyamfi, 2022a) and scientific reasoning (Anim-Eduful & Adu-Gyamfi, 2023) in other chemistry concepts.

The curriculum of senior high school chemistry requires that analytical chemistry be introduced to students through the identification of selected cations and anions (Ministry of Education [MoE], 2010). Students' understanding of most of these selected cations and anions, as required by the curriculum, depends on firm background knowledge of some essential concepts, such as QA, which determines the constituents of a compound or mixture of compounds, is the process of determining what metallic radicals (cations) and acidic radical (anions) are present in the sample without regard to quantities. Moeller (2012) summarized the theoretical principles underlying quantitative or qualitative analysis as; in qualitative analysis, the mixture was put into a solvent such as water (or dissolved in acids) where the dietetic constant of the medium overcame the interionic forces of attraction and in this way putting the ions somewhat separately. The ions in the solution are made to react with the ions of various reagents to bring out the various characteristic changes such as color, appearance, precipitation, and complex formation which formed the basis for the identification of various ions present in the solution (Moeller, 2012).

Notwithstanding the importance of QA in students learning of chemistry concepts, QA has been considered one of the most challenging areas for students in senior high schools (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2022a, 2022b; Treagust et al., 2004; Uzezi et al., 2017) to learn. For instance, in their study, Treagust et al. (2004) established that QA involves more process skills and one had to learn many chemistry concepts to understand the lesson. Skoog et al. (2014) agreed with these assertions. That is, according to Skoog et al., students were unclear about the nature, were tedious and frustrated in testing gases, cations, and anions, using other reagents, and found different apparatus as being specified in the curriculum involving lots of memorization, and linking/applying to previous concepts.

Uzezi et al. (2017) assessed conceptual difficulties in a chemistry syllabus of the Nigerian science curriculum as perceived by high school students and gave the following highlights supporting the extensive nature of QA, making QA a difficult topic for students. In the study, Uzezi et al. sampled 12 concepts, representing 63.25%, as difficult, out of 19 concepts in the curriculum used for the study. From the 12 difficult concepts, five concepts formed the basis of QA. A significant source of difficulty in students' understanding of fundamental inorganic QA identified was the students' difficulties in the "formation of precipitates, complex salts, and addition of acid" (Treagust et al., 2004, p. 727). Reasons for students' difficulties, included a lack of understanding of the procedures and reactions involved in QA. The requirements of QA were not explicit enough for students to understand. Besides, there was content overload in QA, which involved propositional and procedural knowledge, as well as manipulative and inferential skills (Treagust et al., 2004). Other challenges that affected teaching and learning qualitative analysis in senior high schools included inadequate time allocated for teaching chemistry, overloaded curriculum with no clear-cut procedure for teaching (especially practical), poor teacher preparation, unqualified chemistry teachers, poor instructional methodology, and reduced use of instructional materials (Muse et al., 2019). However, the number one factor that leads to students' success is the methodology that teachers use in teaching (Alvarez-Bell et al., 2017). This assertion suggests that despite all the challenges mentioned above, an excellent teaching technique could significantly enhance students' conceptual understanding. The chemistry curriculum contains organizational information about a subject or a topic that guides teachers as to what is expected of them to teach (Kaufmann et al., 2002), and the same is contained in the Ghanaian chemistry curriculum.

In Ghana, the practical aspect of the WAEC chemistry examinations consists of three sections: volumetric analysis, qualitative analysis, and general knowledge in practical chemistry work. These are separate practical components that students must be examined in one paper. QA has three sub-units that students must master as the identification of inorganic cations, inorganic anions, and organic functional groups. The curriculum does not have a structure for the practical chemistry work and does not even state how teachers should teach it and the exact content to cover (MoE, 2010). However, WAEC gives some directives and requires students to know and perform the characteristic tests of cations with dilute $NaOH(aq)$ and $NH_3(aq)$, and with the following ions (NH_4^+; Ca^{2+}; Pb^{2+}; Cu^{2+}, Fe^{2+}; Fe^{3+}; $A1^{3+}$; $and\ Zn^{2+}$). For the confirmatory tests for these listed cations, the curriculum did not specify the reagents to be used.

For the purpose of this current study, we considered the characteristic reactions of dilute HCl on solids or aqueous solutions and concentrated H_2SO_4 on solid samples containing Cl^-; SO_3^{2-}; CO_3^{2-}; NO_3^-; and SO_4^{2-} . We, also, addressed confirmatory tests for these listed anions (without specifying the reagents to be used) and a comparative study of the halogens (displacement reactions). Characteristic test for $H_2, NH_3, CO_2, HCl,$ and SO_2: characteristic test tube reactions of the functional groups in the following organic compounds: alkenes; alkynes (using acidified $KMnO_4$ and bromine in tetrachloromethane solution); alkanols; alkanoic acids, and sugars (using Fehling's and Benedict's solutions only); starch (iodine test only) and proteins (using the Ninhydrin test, Xanthoproteic test, Biuret test and Millon's test only) (WAEC, 2013, pp. 134-135).

Research has shown that most chemistry teachers employ the lecture method of teaching (Iqbal et al., 2009; Kolomuc et al., 2012; Uzezi et al., 2017). Knight (2015) boldly shared the view that most teachers use textbooks in teaching and are seen as repositories of knowledge. There is a need for a methodology that is student-centered, activity-based, and technologically enhanced to equip students with 21^{st}-century skills to prepare students to play a significant role in solving the challenges that they will face. Hence, there should be new ways of thinking creatively, using innovative teaching, resulting in pedagogically sound learning (Lerman, 2014)

The chief examiner's reports (WAEC, 2013; 2014; 2015; 2016; 2017; 2018) showed students' poor performance in QA in the final examinations. For example, the report (WAEC, 2018) was laden with comments such as the “performance for question two (qualitative analysis) was not encouraging. Some of the candidates did not adhere to instructions" (p. 301). These comments suggest that the students lacked relevant skills for adequate QA and inadequate descriptions of precipitates formed. The suggested remedies for these poor performances, according to the report were: a) teachers should start the practical work with students right from first year with more practice in the laboratory, and d) teachers should explain the procedures used in practical activities to students. More practical work needed to be done in the area of qualitative analysis as hands-on activities would enable students to match theory with practical and see the relevance of what they do in life (WAEC, 2018, p. 301).

In 2017 WAEC report, "some candidates did not report on the activity even though they proceeded to work on the filtrate and residue" (p. 265). Many candidates wrote, "precipitate dissolves" instead of "precipitate dissolves to form a deep blue solution" (p. 265). Some candidates did not report on the activity performed. Some who reported also described the filtrate as 'clear filtrate' instead of the colorless filtrate. Others, also used the terms wrongly. For example, “precipitate instead of residue" (p. 267). The suggested remedies for these as proposed by (WAEC, 2017) were:

> The solution to the poor standard of students was simply for teachers and students to work hard in the classrooms and laboratories. Teachers had to use their school laboratories very well. Teachers had to endeavor to expose candidates to a lot of practical exercises and make time to score the exercises while drawing their attention to essential points. In recording tests, observations and inferences should be pointed out to students (p. 263).

Furthermore, in 2016 the following were observed by the chief examiner (WAEC, 2016):

> Poor knowledge of identification of cations and anions in solution, candidates referred to filtrate … and residue as a precipitate. Most candidates, wrote a white solution for white precipitate and a white gelatinous precipitate for silver chloride instead of white precipitate, most candidates did not record their observations and inferences immediately after adding the solutions, hence observations and inferences were mixed up (p. 33).

The reports further suggested these remedies to these lapses (WAEC, 2016):

> Candidates needed to have a thorough grasp of the principles behind the answers they were providing in the practical questions. Such understanding helped in a systematic presentation of answers which demonstrated understanding. Candidates should be exposed to more practical work to obtain the necessary techniques and knowledge required (p. 31).

In 2015 these were the highlights of poor students' performance (WAEC, 2015). Many candidates performed confirmatory tests for cations they had not identified earlier (p. 29). They were not able to make correct observations and inferences; the majority of the candidates were not able to perform the correct confirmatory test for the cation identification (p. 31), and some candidates did not follow the procedures outlined in the question thereby messing up with their answers. Most candidates could not give a detailed description of the gas evolved (p. 33). Also, many of the candidates could not write their observations correctly, and even where they were successfully written, they could not make any meaningful inferences. In this instance, some of the candidates wrote gelatinous solution instead of gelatinous precipitate, and other candidates did not give the color of the resultant solution or precipitate (p. 35). Suggested remedies recommended by (WAEC, 2015) were that "candidates should be exposed to much practical work to enable them to acquire the requisite practical skills. Candidates should be taught how to make correct observations and inferences" (p. 29).

Most of these issues pointed out in chief examiners' reports point to instructional methods employed by teachers, as shown in the suggested remedies. These suggested remedies, therefore, call for a study to explore what could account for students' difficulties in answering questions regarding QA during examinations. Such study will help ascertain: (i) the nature (how difficult) QA concept is to chemistry teachers and (i) the general pedagogy and subject matter knowledge teachers have in teaching QA.

Apart from WAEC chief examiner's reports, several researchers have also alluded to these same weak teaching methods employed by the teachers (Adesoji & Omilani, 2012; Opara, 2014; Sam et al., 2018; Singh et al., 2012; Uzezi et al., 2017). For instance, Adesoji and Omilani (2012) shared that the traditional method of teaching chemistry affects chemistry education. This traditional didactic method of teaching using the lecturing method was predominantly being used in most of our schools (Sam et al., 2018). Student-centered cooperative interactive learning was more effective than the teacher-centered approach (Uzezi et al., 2017). Opara (2014) further expressed that the conventional way of teaching chemistry did not bring out the demand that was expected of a 21^{st}-century student. The problem was compounded by the fact that while the curriculum demanded that students understand the concepts of QA; no particular instructional strategy was stated. However, none of these studies have focused on exploring how teachers use their general pedagogy and subject matter knowledge in QA to teach QA to help maximize students understanding in QA. Treagust et al. (2004) advocated a 21^{st}-century teaching methodology that had the pedagogy in teaching QA to boost the confidence, knowledge, attitudes and skills of students in solving modern-day challenges. This 21^{st}-century methodology should have the ability to concretize abstract concepts and improve the retentive memory of students.

In another development, teaching QA involves activities of identifying cations and anions through performing a flame test, pouring of reagents, holding of test tubes, wafting to smell gas evolution, and filtering solutions, all of which demand students' involvement (Olajide et al., 2017). Based on the nature of teaching and learning processes demands instructional strategies that actively involve students. For instance, Ajayi (2017) asserted that hands-on activities enhance students' learning experiences and students handling apparatus and chemicals in the laboratories enhance their understanding and increase performance (Abdullah, Mohamed, & Ismail, 2007). Many other terms are used to describe hands-on activities in the literature, such as practical activities, manipulative activities, and material-focused activities (Ajayi, 2017). The reason for placing so much emphasis on practical activities is that they can help in retention of students' knowledge for a longer time than the other instructional strategies (Kozleski, 2017).

Teaching is an act that is continuously metamorphosing, making teachers reevaluate their ways of imparting knowledge. This depends largely on the pedagogy, content knowledge, and now, more importantly, the technological ways to communicate the aspect of teaching, be it theory, practical, or a blend of the two. The traditional understanding of teaching is someone imparting knowledge to another person. This transfer can be understood from many approaches. A look at some learning theories could help shed more light on why a particular choice of learning theory may be more suitable for teaching and learning of QA. According to Ali (2012), learning is influenced by multiple factors, including teacher preparedness to resource access. However, others have extended the range of necessary educational factors (Adesoji & Omilani, 2012; Uzezi et al., 2017). Adesoji and Omilani (2012) asserted that something as basic as comprehension of the subject matter by the teacher him/herself must be factored into the learning process. Uzezi et al. (2017) traced poor learning to poor performance in qualitative and quantitative analysis in chemistry. One of the contributing factors associated with students' poor performance, according to Nbina (2012), is how chemistry teachers teach. Ali (2012) held that students with poor educational backgrounds, including a lack of individualized attention, prevent solid teaching in later forms. The inability of teachers to make connections with relevant previous knowledge and experiences in a context that students are familiar with is another contributing factor (Treagust et al., 2004).

Additionally, Tan et al. (2001) stated that when it comes to teaching QA, the learner needs to know the structure of the content. Teachers must pinpoint the ideas, schemes, facts, process skills, and strategies required for teaching QA. According to Tan et al., a basic understanding of the content of QA must not be presumed in students who probably require a rudimentary review of QA. If students are aware that they are to apply the concepts and knowledge learned in QA lessons to the experiment they perform, with the process skills acquired, the learning of QA becomes meaningful. To help bring about conceptual change, teachers, as well as students, must be aware of factors impeding comprehension (Adesoji & Omilani, 2012). To Sağlam and Şahin (2017) the sole responsibility of every teacher is to help students attain mastery of their learning through the use of sound pedagogy in teaching. In other words, the teacher must develop, update, and upgrade him/herself in his/her areas of competencies to help students understand the concepts. It was, therefore, necessary to explore how chemistry teachers use in a context of their general pedagogy and subject matter knowledge in QA to teach QA in senior high school for students to appreciate the vital role QA plays in our society. Based on this purpose, this study seeks to answer the question: *How do chemistry teachers use their general pedagogy and subject matter knowledge of QA and in what context do they teach QA to students in senior high schools?*

The findings of this study on teachers' general pedagogy and content knowledge in QA on how teachers teach QA to students would inform chemistry educators and researchers of the pedagogy, content, and context within which teachers use their pedagogies to instruct the content of QA. Chemistry educators and researchers could take advantage of any theory linking pedagogy, content, and context and conduct further research on how context influences teacher pedagogy and the content of chemistry. Again, Findings on how teachers teach QA to students at the high school level could be a revelation as there could be issues with how teachers prepare to teach and how they implement their intentions in the classroom.

Research Areas, Participants, and Methods

The study made use of a qualitative approach. Under the qualitative approaches, this study specifically made use of descriptive phenomenological qualitative research design (Morse et al., 2021) to help explore chemistry teachers' teaching of QA in the senior high school for a piece of in-depth knowledge and understanding. Descriptive phenomenological research design did not only help to obtain the views, feelings, and assumptions of teachers about the teaching of QA (Creswell, 2012), but also highlighted the lived experiences and perceptions of senior high school chemistry teachers on how they teach QA.

The area of study for this research was the Central Region of Ghana. The region had the hub of second-cycle institutions in the country. This region was chosen because of the rich educational institutions that it was endowed with. It can boast two traditional universities, one technical university, three colleges of education, and some of the best second-cycle schools in Ghana. Though the region had all these best second-cycle schools, there were several schools from other parts of the region within the category of less-endowed schools. Therefore, there was a blend of both endowed and less endowed schools for consideration in this study. To achieve this, three catchment areas within the region were considered; Cape Coast Metropolis, Mfantsiman Municipality, and Abura/Asebu/Kwamankese (AAK) District. These three catchment areas were chosen because they had all the categories of schools; grade A (well-endowed) schools, grade B (endowed) schools, and grade C (less-endowed) schools as in the other districts within the region. Another reason for choosing these three areas was to reflect the nature of teaching and learning with the infrastructure and opportunities that each area had.

Participants for this research were selected through convenience and purposive sampling techniques. As mentioned earlier, Cape Coast Metropolis, Mfantsiman Municipality, and AAK District in the Central Region were selected purposively. The selection of the three area was informed by the performance of the schools in chemistry examinations by WAEC, school type according to Ghana Education Service categorization, and the location of a school in the region. A grade A school was selected based on the weak performance of students in chemistry from the Cape Coast Metropolis. The only grade A school in the Mfantsiman Municipality was selected by convenience to participate in the study. From grade B schools, one each was selected from the three areas based on students' performance in chemistry examinations. Since there was only one grade B school in the AAK District, it was selected through a convenience sampling technique. Also, one grade C school each was selected from the three areas. Though the grade C schools were less endowed, the three were selected based on their weak performance in chemistry examinations conducted by WAEC. In all, eight schools were chosen, consisting of two grade A schools, three grade B schools, and three grade C schools. The purpose of selecting chemistry teachers from schools in these three areas was that they had characteristics that could adequately address the research objectives in terms of experiences of teachers teaching in the various schools and the conditions under which teaching and learning take place.

Science teachers teaching chemistry in the eight schools participated in the research. Hence, all teachers teaching QA (chemistry) for at least 2 years interacted with us through interviews. Thereafter, the participating teachers were stratified into three groups concerning their teaching experiences. The three groups were 1-5 years, 6-10 years, and above 10 years. In each of the eight schools, at least one teacher currently teaching QA and willing to have his or her classroom observed by us was selected to participate in the lesson observations. The teacher's experience was a factor in the selection, as teaching experience is seen as influencing teacher pedagogical content knowledge (Chu et al., 2015; Wei & Liu, 2018). Due to the outbreak of the Covid-19 pandemic and ensuing restrictions at the time of data collection only 10 teachers of the targeted 24 teachers teaching chemistry participated in the research. Hence, the 10 teachers who participated in this research were selected through convenient and purposive sampling techniques.

The Modes of data collection were interviews, Teacher Interview Schedule on Qualitative Analysis (TISQA), observations, Teacher Observation Schedule on Teaching of Qualitative Analysis (TOSTQA), and field notes. This interview, TISQA, approach was appropriate for collecting data from participants in this study because of the aim of the study and as such it allowed respondents to express the rich experiences that they have had in their respective jurisdictions about teaching QA. The nature of the interview was face-to-face interaction with teachers using the self-developed TISQA. TISQA helped to explore issues that may have had a direct or indirect impact on teaching QA by teachers. TISQA had two themes with five prompt (minor) items. The purpose of the minor items was to further guide the direction of the interviews to help measure what context teachers teach QA. In addition, TOSTQA was used to augment the content knowledge and pedagogical skills of participants in the teaching of QA. The nature of this schedule was marked by ongoing note-taking with categorized in situ, observer-as-participant where our presence was known by the participants but less contact during the period of observation (Cohen et al., 2007) on teaching and learning QA.

Concerning the validity and reliability of TISQA and TOSTQA, the items on both TISQA and TOSTQA were constructed based on a review of the literature and the second and third authors' years of teaching experience in senior high school. To ensure the credibility of TISQA and TOSTQA, three researchers peer-reviewed the instrument to check whether it could measure what it was supposed to measure. Their suggestions were used to improve the instrument. Thereafter, TISQA and TOSTQA were given to research experts to critique and make suggestions which further improved the quality of the instrument. The suggestions from research experts were used to improve the credibility of TISQA and TOSTQA. The revised and improved TISQA and TOSTQA were pilot-tested in three schools and transcribed data were sent to participants to member-check their interview schedule to ascertain their credibility. To further ensure the credulity of TISQA and TOSTQA was a triangulation of the responses from three pilot tests on each item to ascertain no ambiguity in the responses. To ensure the dependability of the interview schedule, the authors kept all originally drafted interview questions with the revised versions, as well as the unedited audio tapes, field notes, and transcripts, intact for future reference. At each stage of data collection, participants were given the opportunity to member-check their transcribed observed lessons or Nvivo quotes. Biases were constantly reflected upon through reflexivity because of the researchers' background as chemistry teachers. The dependability of TISQA was its reproducibility, as it was used in different areas of the Central Region. Again, all materials and processes used in constructing the instrument were kept in their original forms for audit trial.

The field notes gathered primarily contained observations made, reflections, and memos on the day-to-day unfolding of events in the classrooms. A detailed well-written note with dates, times, and events characterized this field note. It documented sequentially events with participants, insights, interactions with materials, questions, and other things that needed documentation. Observation made in one area was triangulated with the rest of the areas in the field notes. The reliability of this instrument was its chronicled documentation and ability to produce all notes reading to the final theory generation.

In all, 11 weeks were spent on the data collection procedure, cleaning and uploading; reorganizing and exploring; coding and visualizing; and exporting and communicating. This involved formatting all the documents needed for analysis and organizing them into the Nvivo software for analysis. Thereafter, they were reorganized and explored for all other documents to be in sync. The coding and visualizing of data processing and analysis saw the coding, sorting, synthesizing, and visualizing of the data using Nvivo software that assisted and managed data analysis.

Results

Theory of Pedagogy, Content, and Context of Teaching QA

The first thing to consider when teaching QA is for teachers to take a critical look at their content, and context. In this rule, teachers teaching QA are mandated to stop and assess their content knowledge, and the context in which they teach. Therefore, this presentation will highlight both the emerging issues from the research question and the distinctive issues that the question addressed respectively. The emerging issues were the content and concept of QA and time allocation. The chemistry curriculum has two main parts which focus on the nature and structure of the syllabus and the difficulties encountered using the curriculum.

Content and nature of concepts of QA

The content and concept difficulty shared amongst most teachers indicated that the content, which is the constituent topics of QA, and the concepts which are knowledge of QA are not difficult for teachers to teach nor too high for students to grasp. Those who shared that the concepts and content are neither too difficult nor too much expressed themselves:

For me, QA is not all that difficult to teach … It is quite broad and you have to get into the syllabus to pick out what is required (Sam, a Teacher).

… it is not that difficult to teach qualitative analysis but you will need to go through the syllabus very well (Lizzy, a Teacher).

Teachers explained that teaching QA to students only becomes difficult when students do not have knowledge of the basics of QA. Excerpts to support this assertion are:

… Only if the students know the basics. Year after year I look to equipping my students with knowledge in the basics (Baba, a Teacher).

I first try to teach students the fundamentals of qualitative analysis and make teaching it less difficult … (Sam, a Teacher).

Teachers who shared the difficulties of the concept associated it with other factors and not so much about concepts found in the curriculum. For example, Lizzy mentioned that:

Experienced teachers perceive the content of QA not to be difficult while less experienced teachers look at it differently (a Teacher).

Justice, an experienced teacher, expressed that;

They are not too difficult to teach; most of these become difficult when the teacher does not approach them well (a Teacher).

Since the approach to teaching QA is not clearly spelled out, it is more prudent to complete the theoretical aspects, which are the basics before the introduction of the practical-based lessons. This minimizes the difficulty with which QA is taught to students. Excerpts to support this assertion are:

If you learn the theory aspects, you need to practice those aspects of the practical work in the theory before getting to the qualitative analysis. So when you get there, it makes the teaching qualitative analysis easier but some teachers treat qualitative analysis as one topic (Ben, a Teacher).

Just using the syllabus to teach qualitative analysis straight away is not the best, there should be a pre-lesson before teaching qualitative analysis (Mike, a Teacher).

Lizzy, a less experienced teacher, shared that:

They are not difficult unless the teacher does not explain them or demonstrate well to students how these concepts are formed. Since they have done some solubility, it will help them to understand QA (a Teacher).

The question of the clarity of QA in the curriculum came up with a strong viewpoint. The content to be taught in the curriculum is clear; but not detailed in its present state. For example;

It is clear as to how you have to teach it. It will tell you what the students should learn at the end of the lesson. How you will make sure those objectives in the syllabus are achieved is up to you the teacher (Sam, a Teacher).

The syllabus is not detailed enough for a novice teacher and also not clear, on how to present and record your test, observation and inferences are not in it. It should be clear so that any teacher can pick the syllabus and know what to teach (Baba, a Teacher).

Other curriculum materials should be read by teachers to appreciate the clarity of the content of QA in order to effectively teach it to students. Sam further explained that;

… it is clear as to what students should know. I also think it is best to use the WAEC-recommended syllabus in addition to the GES syllabus (a Teacher).

Notwithstanding teachers claim that QA is not difficult to teach, there are aspects that are difficult for students to learn. The teachers posited that:

… One thing about qualitative analysis is that we need to know the difficult aspects such as the testing of the anions, and making students understand precipitation reactions, acids, and bases reactions (Mike, a Teacher).

... The concept of precipitate should be taught under acids, bases, salt, and solubility; if not, it becomes one of the difficult topics (Justice, a Teacher)

The difficulties of students in learning QA are associated with the formation of complexions, distinguishing between gelatinous and chalky precipitates, and the addition of acids. For example, Anthony pointed out that;

The formation of complex compounds is highly difficult for students to understand. Sometimes you teach it over and over and you realize that most of them have not gotten it so you leave it and move on (a Teacher).

In terms of a precipitate, my students do not have a problem with understanding what a precipitate is or detecting a precipitate, but for the complex salts and addition of acids, it is a problem for them (Coffie, a Teacher).

Baba explained that;

The formation of complexes is also another difficult concept for students to understand … because the students do not have enough background knowledge as to why some precipitates are formed and why some dissolve and others do not (a Teacher).

Language is a major tool that students are lacking, causing the difficulties students have on differentiating between gelatinous and chalky precipitate. Sam mentioned that;

Sometimes distinguishing between gelatinous and chalky precipitate is difficult. The language used in teaching can also make it difficult for the students to understand (a Teacher).

I see it as a language problem. The ability to differentiate between the chalky and the gelatinous precipitate, although you tell them they mess it up at times by shaking the test tube as they add the chemicals in drops (John, a Teacher).

Though some concepts are difficult for students teaching experience is the solution to teaching those concepts to them. Because, with sufficient teaching experience, teachers will be able to adopt the most appropriate instructional strategies to support students in learning QA. For example, Baba mentioned that;

I do not have any difficulty in explaining these concepts to my students the topics they see as difficult … just because I have taught it for a very long time and can select the best approach to help my students learn in the laboratory and practice (a Teacher).

Content and context of the syllabus (Chemistry curriculum)

The nature of the curriculum as identified poses a problem to teaching and learning QA. The exploration of the concept of QA in the curriculum used in teaching revealed a seemingly not united front on the use of the curriculum as a guide. From observation and analysis done on the curriculum, it was a fact that QA was not specified under any particular topic or as a substantive topic to be taught at any stage. The chemistry curriculum that the GES used in schools had bits and pieces of the concept spread in it. For instance, precipitation is taught under Periodic Chemistry and continued from Solubility. It is also a fact that the curriculum did not contain a separate section on any practical but all built within the theory and teachers have to decipher. As noted earlier, the curriculum does not give a context to teaching QA. Excerpts to demystify this assertion of the selected teachers are:

No, it just tells you, that these are the ions, you have to detect, so I can say that the syllabus does not give direction to how to teach these concepts (John, a Teacher).

The syllabus only lists some process skills that the students will develop as they (students) go through the topic in the syllabus but does not give direction to how they should be taught (Justice, a Teacher).

The syllabus gives just the general guidelines but not specific (Mike, a Teacher).

Since there are no clear-cut instructional strategies in the curriculum for teaching QA to students, teachers have to rely on their ingenuity and resourcefulness to teach. Excerpts to support this assertion are:

So it comes back to the ingenuity of the teacher. The teacher has the ability to make the subject matter. The teacher needs to try to do so many things and see the one that will be okay for the students (Justice, a Teacher).

You need to be resourceful to deduce the specifics of it and teach it in the most appropriate ways (Mike, a Teacher).

… you have to go the extra mile as a teacher to teach QA. The approach is limited, but it gives some suggestions as letting the students do this experiment and then add this reagent to the other, that is not enough and so the procedure there is not any proper structured procedure (Coffie, a Teacher).

The concept of QA is not treated as a major topic in the curriculum. However, it is treated as sub-concepts under major ones such as acids, bases, and solubility. These sentiments expressed by the teachers were true as we verified from the chemistry syllabus. Coffie mentioned that;

There is no major topic in the syllabus on qualitative analysis … it can only be seen under some other major topics. If I teach acids and bases, I know I have to do experiments (that is, practical) on it. The ions to be detected will be listed for the teacher to consider (Coffie, a Teacher).

To appreciate the context of teaching QA effectively to students, the teacher has to consult other curriculum materials with elaborate procedures and approaches to teaching the concept:

… you the teacher will have to consult some other materials or textbooks to get some of these procedures for teaching your students (Coffie, a Teacher).

The curriculum material that has been helpful to chemistry teachers is the WAEC syllabus which gives an elaborate procedure. Max explained that:

… but the direction is not that clear, and so you the teacher, have to find some other means of adding up to what is in the syllabus in other to teach your student. The WAEC syllabus has been helpful to us (teachers) so that we can learn and understand the concept. I hope you know WAEC is the examination body (a Teacher).

Though using the curriculum together with other curriculum materials is crucial, teachers should structure the concept of QA for effective teaching and learning. For example, Anthony mentioned that:

You cannot teach them all together, you need to structure it. You need to teach those distinctions that will give you the color changes and the ones that will dissolve so it is structured to help students assimilate (a Teacher).

… under various topics that make up qualitative analysis. You have to sort out the various aspects and bring them together, strategize so that you can teach the concept very well to students' understanding (Lizzy, a Teacher)

In an attempt to structure and organize the content of QA for students in the senior high schools, teachers need to be cautious in grouping sub-contents of QA. If the sub-contents of QA are well-grouped, students easily assimilate. Anthony expressed that:

… you need to know how to group them and attend to them so that students will assimilate them easily. If care is not taken you will finish teaching (i.e., practical) and the students will not get what you taught them (a Teacher).

Also, there are few authentic textbooks in the system where teachers can make inferences and that depends on the ability of the teacher to gather what is required from the curriculum to make a meaningful presentation. For instance, Lizzy opined that the curriculum:

… the syllabus did not give a full exposition on the content of qualitative analysis. You have to do more research on the topic from good books before you will be able to teach it right (a Teacher).

Our observation of the chemistry curriculum (teaching syllabus), as the investigators, revealed that the context of the curriculum was explicit. That is, the planners of the curriculum recommended that students should be well-prepared prior to practical work and that practical work should begin in the second year of the 3-year program. According to MoE (2010, p. iii);

Teachers should ensure that students are adequately prepared before each practical class.

Teachers should also ensure that practical classes are started in the second year alongside the theory classes.

There were suggested activities to guide the teacher's instructional strategies and when to teach QA to students. This was not necessary at the end of the 3-year program. For instance, in SHS 2 under Unit 1 of Section 2 (Inorganic Chemistry), the planners of the syllabus suggested that;

Students should perform simple experiments to compare the thermal stabilities of Na_2CO_3 *and* Li_2CO_3 *or* $CuCO_3$*;*

Test for any gas that evolves by passing it through lime water (MoE, 2010, p. 24).

Also, in SHS 2 under Unit 6 of Section 4 (Acids and Bases), the planners suggested that,

Perform preliminary and confirmatory tests to qualitatively identify the ions Pb^{2+}, Ca^{2+}, Zn^{2+}, Al^{3+}, Cu^{2+}, Fe^{2+}, Fe^{3+} *and (*Cl^-, Br^-, I^-, SO_3^{2-}, SO_4^{2-}, S^{2-}, CO_3^{2-}*) in solution using appropriate reagents (HCl, NaOH,* NH_3, $BaCl_2$, $AgNO_3$*).*

The content of QA is not difficult for teachers but students' lack of background knowledge and language are contributing factors to their difficulties on QA. However, teachers can use the most appropriate instruction approaches to help students overcome their learning difficulties on QA. The less experienced teachers may not have the needed PCK to transform the content of QA to students as compared to the experienced ones. That is to say that teaching experience (Treagust et al., 2004) is a key to effective teaching of QA to students. Commenting on the role of context, Harris and Hofer (2009) shared that it is important, as it affects the sensitivity of the whole system of teaching, in which teaching QA needs to be considered. Teachers see the content relating to QA as less difficult to teach but difficult for students to learn although Anim-Eduful and Adu-Gyamfi (2022b) reported that teachers see the content as abstract and difficult. Based on the document analysis of the chemistry curriculum, the context of teaching and content areas are clearly spelled out in the curriculum (teaching syllabus), and the teacher's claim otherwise has no basis. It is either teachers hardly consult the curriculum or do not know how to implement the recommendations and suggestions of the curriculum. The curriculum recommends that teaching QA to students should start in the second year alongside the theory to give students sound knowledge prior to practical work. This confirms the findings of Svehla (2008) where pre-requisite concepts are to be taught to students to facilitate their understanding of QA. The curriculum is also clear in the number of periods for teaching theory and practical works of which QA is inclusive. There are six periods of 40 minutes but not four periods. Teachers together with their respective schools may not be implementing the chemistry curriculum as planned with respect to the required time for effective teaching of chemistry in the senior high school. Hence, the supervisory bodies of the Ghana Education Service should intensify their supervision to ensure that chemistry teachers implement the curriculum as planned. Also, management of senior high schools should organize professional development sessions for teachers to appreciate and enact the chemistry curriculum within the planned content and context.

Theory of How Teachers Teach QA

Furthermore, the study explored how teachers use their content knowledge to teach QA to students at the SHS level. The main theme here is the instructional strategies teachers employ. It is vital to talk about teachers' approach to teaching and perceived students' difficulties, process skills, and workload in the teaching of QA. Based on the interviews with the teachers on how they teach QA, various approaches used were identified by the teachers. Views of teachers were revealing and John an experienced teacher and Lizzy a novice teacher captures how most other teachers teach QA. The views of John and Lizzy are reported in this section.

Introduction to a lesson should begin with sharing of significance of learning QA as a new concept to gain students' attention. Thus, according to John (an experienced teacher),

First of all, you have to tell the students, what you are going to do. Then you tell them the application of what you are coming to teach in the industry so that you do not lose the attention of the students, the moment you lose the attention of the students at the beginning, that is the end. You have to capture their attention that is, what I am coming to teach is applicable in the industry such as the Ghana Standards Authority, where they analyze the content of drugs; the mining industry where they analyze metals (minerals); the water research industry where they analyze the pollution level of water; the environmental studies where they analyze the pollution level of particles in the air.

Then you move on to tell them that qualitative analysis, is in two parts; … preliminary analysis and the confirmatory tests.

The preliminary analysis is also in two parts; … physical observation of the salt, you show them the colors of copper, the colors of iron, and those that are not colored like lead, and aluminum. And in the second part, you tell students that qualitative analysis is done in solution. You are testing for ions.

Development of content where teacher uses his/her knowledge of general pedagogy to transform the subject matter of QA concepts to the scientific understanding of students. According to John,

The substances that you have are solids but it is the ions that we are testing for so there is the need to dissolve it in water so that we can test for it. The volume of water that you will add to the sample must not be too much. On average, we will say 10cm^3 of distilled water.

You need to dissolve it in distilled water so that you do not introduce extra ions. If you use tap water and maybe you are finding calcium, the tap water already has calcium ions in it (to help strengthen our bones). You might be finding the wrong ion … the solution must not be too dilute, that is why, it is advisable to use about 10cm^3 of water to get the specified results.

There is a technique in adding the solutions, you must not add it anyhow because you want the best *results. You have to take just about 2cm^3 but there is no point using the measuring cylinder to do that. Using our normal test tube of this size, you just fetch a little, if you want to be so sure of what 2cm^3 is, then you can use the measuring cylinder to fetch it inside and get to know what volume exactly to use. … if you take too much sample, the results may be so confusing, that you may not be able to tell exactly the nature of the precipitate that was formed. You have to use just about 2cm^3 and start to add dilute $NaOH_{(aq)}$, which is the chemical for the preliminary analysis.*

… $NaOH_{(aq)}$ is added because of solubility rules, the hydroxides of most cations are insoluble. The idea is for us to form precipitates and based on their nature and color, we will be able to start some deductions. When you add dilute $NaOH_{(aq)}$, you will form a precipitate. When you see a white precipitate, all the ions that are colored are not there. All the ions that are colored are Fe^{2+}, Fe^{3+}, and Cu^{2+}, straight away, you eliminate them. You have Pb^{2+}, Ca^{2+}, Al^{3+}, and Zn^{2+}.

You need to go further by differentiating between them, so then, you introduce adjectives. It is white and fine, but other adjectives will separate them, such as chalky precipitate or gelatinous precipitate. The moment you introduce an adjective, you eliminate two of the ions straight away. When we say white chalky precipitate, then we are going in for Ca^{2+} and Pb^{2+}. That is what teachers have not been able to emphasize.

I normally prefer to add their charges because we have other charges. Both Pb^{2+} and Ca^{2+} cannot be there. You have to write it as Pb^{2+}/Ca^{2+} or you use the word 'or' between the two cations. If you rather write Pb^{2+}, Ca^{2+}, you will be marked down because you are saying that both of them are present but both of them can never be present. They will interfere with each other. Since we are saying that it is only one cation that is there, we need to go further and differentiate them again, because we are narrowing it down small, small. Also, we use the fact that some cations are amphoteric, and others are not. Pb^{2+} will dissolve in excess dilute $NaOH_{(aq)}$ but Ca^{2+} will not, that is the purpose of adding in drops and excess. After you have gotten your observation for adding in drops and you do the inference for in drops, you do the same for in excess too. If you add in excess, you shake, it is important because it increases the reaction rate by collision, so when you shake and the precipitate dissolves then you are going in for Pb^{2+} because you know Pb^{2+} is soluble, if it does not dissolve then you go in for Ca^{2+}. You have sorted Ca^{2+} and Pb^{2+} out.

Then you go to the next cation which is aluminum. Originally, it is white, assuming you added and had a white gelatinous precipitate. If you add dilute $NaOH_{(aq)}$ in drops, you may not be able to tell whether it is chalky or gelatinous. Hold the test tube as if you want to pour the solution out and return. If it is chalky, it will start draining from the side down and if you give it two minutes, it will settle from the top and the top will become clear, that is the nature of chalky precipitate. In examinations, you do not have the laxity to do that, but if you want to be double-sure. Do one test and leave it, leave the inference for the meantime. The chalky precipitate will settle. For gelatinous precipitate, stick to the side of the test tube as if you are dealing with starch. Depending upon the concentration, sometimes, it is very thick.

The right concentrations of the ions are important. If the ion is too concentrated and you add the excess, it will still not dissolve. That is why preparing the right concentrations is important. With experience, you do not need to prepare the right concentrations. Add a little water, and dissolve it. Ideally, under standard conditions, you need to prepare the right concentrations. It varies but it is often around 0.1mol/dm^3.

Zn^{2+} and Al^{3+} are all amphoteric. Their hydroxides are amphoteric. So you cannot use dilute $NaOH_{(aq)}$ to dissolve them. In drops, both Zn^{2+} and Al^{3+} give you a white gelatinous precipitate, and in excess, both of them dissolve, you will not know the difference. That is where dilute aqueous NH_3 comes in. Dilute aqueous NH_3 does not produce enough hydroxides because it is a weak base. So, the ksp of the hydroxides of the metal will be different for dilute $NaOH_{(aq)}$. When you use aqueous ammonia, you get small hydroxide ions. Aqueous ammonia and water also produce hydroxide ions because it becomes ammonium (hydroxide). The $Zn(OH)_2$ will dissolve in excess but aluminum hydroxide will not dissolve in excess. The ksp will not be exceeded for $Al(OH)_3$. What differentiates the white or colorless in solution is that in solids they are white, and in solution they are colorless. For the ones that have color, they are so clear. Some solids have confusing information, at times you see blue, and you might think it is Copper (II). There is a technique that is used depending on whether it is crystalline or not but Copper (II) Carbonate is powdered, and is light blue, Copper (II) Sulphate is a little crystalline, Iron (II) is also crystalline and

it is pale, with that you can sort them out before you start giving their inference. For the irons, the ones which are colored, when you add dilute $NaOH_{(aq)}$ *the colors become so clear if it is copper, it is deep blue and no other solution hydroxide is colored so that the moment you get it, you know you are targeting* Cu^{2+}*. If you get green gelatinous precipitate you know you are targeting* Fe^{2+}*, reddish-brown precipitate, you know you are targeting* Fe^{3+}*.*

To carry the test to the next level, you need to do a confirmatory test to be sure that the ion that you are seeing is probably present, that is why from the beginning of the preliminary test we do not say confirmed, we simply say present or may be present but when we carry out the confirmatory test, we are specifically targeting a particular ion based on its behavior. Each of them specifically has a confirmatory test reagent. For instance, if you add an acidified solution of sodium oxalate, then you are targeting calcium, when the question says to use ammonium sulfate solution, then you know that you are targeting calcium, so if you add a few drops of that to the test solution you will have a white precipitate. So, we say calcium is confirmed because no other ion behaves that way. Previously, you started suspecting calcium. This test you just did confirms that it is calcium that is present. You cannot say at the beginning of a test that calcium is present and then do a confirmatory test for zinc. It cannot happen that way. During the preliminary analysis, you cannot say that Ca^{2+} *or* Pb^{2+} *may be present, then you do the confirmatory test then you say that* Zn^{2+} *is present.*

At times I tell my students they do not have to memorize the confirmatory test reagents except they are writing NOV/DEC or theory examinations where you might be asked which of the following ions can be confirmed by so and so. In an examination condition, if you see a confirmatory test reagent you will know because they are not the normal dilute aqueous sodium hydroxide or aqueous ammonia and dilute $HCl_{(aq)}$ *that we have, even if you have forgotten you can take the confirmatory test reagent bottle, add a little, whatever you observe, record it and by adding confirmed. When you do that 99% of them are correct.*

Closure of lesson where teacher has to assure students that instructional approach in this QA practical lesson in the laboratory used in this case is the best. Students will only need to follow through the process to attain the needed scientific understanding. According to John (the experienced teacher),

Students do not have to memorize a whole lot of the confirmatory test. It is good for students to know it, especially for quizzes and other purposes. In reality, the average student does not have to commit all the QA tests to memory. You have to just read through and understand them. In case you see a strange reagent just add it and record your inference. There is a technique for performing tests, especially during the examination period when you are stressed. Again, a confirmatory test is done for you to be sure that the ion you have or suspected earlier on is the same ion that is present. That is why we do the confirmatory test. What I have said so far closes the chapter on cation analysis.

Development of concept, there should be another practical lesson to develop scientific understanding of students in other cations that cannot be learned (studied) using $NaOH$ as a reagent. According to John (an experienced teacher),

For amphoteric oxides, there are some actions you cannot differentiate them using dilute sodium Hydroxides like Zn^{2+} *and* Al^{3+}*. They are hydroxides, they will react with dilute* $NaOH_{(aq)}$ *and dissolve, so you will not know which is which. Luckily for us, the addition of dilute aqueous ammonia produces few ions of the hydroxides, therefore you can use it to differentiate between amphoteric oxides because one will dissolve but the other will not dissolve in it. I also use an acronym to know which one dissolves in excess and which one does not. I call it LAZ CuZ CuFeCa LAFe where they stand for the following respectively, L - Lead ion, A - Aluminium ion, Z - Zinc ion, Copper ion, Iron 2+ ion, Calcium ion, Lead ion, Aluminium ion and Iron 3+ ion.*

LAZ are ions that are soluble in excess dilute sodium hydroxide, CuZ refers to ions that are soluble in excess dilute ammonia, CuFeCa illustrates ions that are insoluble in excess dilute sodium hydroxide and LAFe exemplifies ions that are insoluble in excess dilute ammonia. LAZ CuZ CuFeCa LAFe further elucidates the color and nature of each precipitate formed during the test for cations. It has expatiated as follows: Pb^{2+} *white chalky ppt,* Al^{3+} *white gelatinous ppt,* Ca^{2+} *white chalky ppt,* Cu^{2+} *light blue gelatinous ppt,* Fe^{2+} *green gelatinous ppt,* Fe^{3+} *rusty brown gelatinous ppt,* Zn^{2+} *white gelatinous ppt.*

The aqueous dilute ammonia is needed to differentiate between the Cations you cannot differentiate *using dilute Sodium hydroxide. The reason is that ammonia does not generate enough Sodium hydroxide ions. Also, Aluminum hydroxide and Zinc hydroxide, they have their ksp being different. A precipitate will only form when the ksp of the ionic compound is exceeded. Ammonia is not producing a lot of hydroxide ions, therefore the ksp for Aluminium hydroxide will not be exceeded.*

Development of QA concepts of anions where the teacher may have less or no difficulty in teaching because the anions are specific, and with students' experiences in QA of cations, students can easily make scientific meaning of the anions. According to John (an experienced teacher),

The anions are more specific and the dilute sodium hydroxide will give you options; the anions are specific. We have different solutions you can use for them but dilute sodium hydroxide and aqueous ammonia for all the cations. With a little recap, hydroxides of sodium and ammonium ions are soluble. If you add dilute sodium hydroxide and you do not see any precipitate, what then do you do? You can go in for sodium and ammonium possibly present. Add excess dilute sodium hydroxide, then you go and heat. All these ideas are for the preparation of ammonia gas. Ammonium ions, when they come into contact with excess hydroxide ions and you heat them, and ammonium ions decompose. Based on the smell and all that you can know that ammonium ion is present but sodium ion is absent. If no precipitate is formed, just write, no ppt formed, then go in for sodium and ammonium and then differentiate them by excess dilute sodium hydroxide.

The anions have been categorized into two. Three anions will always give you a gas during your test, they are CO_3^{2-}, SO_3^{2-}, *and* S^{2-}. *In the old system, it will be called carbonates, sulphates, and sulphides. They come from weak acids so when you add strong acids their gases are eliminated. That is our preliminary line of test for anions, even if you are not asked, that is the first thing you must do to know which anion is present. You have to add dilute mineral acid. HCl,* H_2SO_4, HNO_3, *and then as you add it, observe the reactions well. The purpose for your adding the acid is, that you suspect that gas might evolve. The moment you add, you look out for gas and when gas is evolved, you have four levels of identifying them. The way the gas comes out, the color and smell of the gas the test of the gas, and further chemical tests like lime water for testing for carbon dioxide or acidified potassium dichromate used to test for* H_2S. *When you add the acid, try and smell it. The gas may not come out quite a lot so you have to bring it closer to your nose that is where the danger is, especially when a pungent smell comes out. Whenever aqueous ammonia is added, you will get a precipitate.*

When the gas comes out, you can identify the ion. For example: if you add the acid and you see a colorless, odorless gas evolving, at times it changes wet blue litmus paper to red, at other times it does not change too much because CO_2 *is a weak acid. Some authorities say that it changes to a claret that is light red. You can also pass it through lime water but if it is not done well, you might not see the milky precipitate, especially when you overpass it through the lime water, it will change to colorless. At times, I grind* $CaCO_3$ *and give it to students so that they will get enough* CO_2 *as an inference. At other times during the test, you might not get enough* CO_2 *but if you do not write the answer you will lose marks, so I tell my students to write the answer once they have observed gas.*

Since the CO_2 *comes from carbonates, you have to write the presence of* CO_3^{2-} *then you have scored 5 marks then you move on. For observation correctly alone, you score 3 marks. Identifying the gas correctly, you score 1 mark, and the ion correctly, you score another 1 mark.*

The other gases have certain smells like H_2S *has a rotten egg smell,* SO_2 *has a pungent irritating smell, etc. So, during the test for anions, the smell is first followed by the precipitate. In examinations, you just have to use the technique and write the answer but you have to look around and see if the other reagents that were supposed to be used are there before writing your inference. In examinations, you adopt a strategy using the knowledge that you have gained in class to get your answers.*

Closure of lesson where teacher has to assure students that testing for anions had ended, and predict the other likely situations that could happen when testing for anions. According John (an experienced teacher),

That ends the test for anions.

At times, you will be given the solid in a bottle and instructions, say add $10cm^3$ *of water. Students must* *learn to record the test because it carries marks. It must be recorded as say Sample F + 10cm^3 of distilled water. The reason for doing that is to find out whether the solid dissolves in water or not. Under observation in your table of presentation, you have to write, solid dissolved or solid partially dissolved.*

If you were given a mixture, then you might be asked to filter. When you filter, you will be asked about the color of the filtrate and the color of the residue. With the filtration, you can sit by it for 10 minutes that is if you do not fold your filter paper well. My advice to students always is that when they get a little filtrate, they should start working on it whilst the rest is filtering, they should not just fold their arms and watch for the filtration to be complete before they continue. This one is just practical knowledge; you have to apply because examination papers will not tell you. After the filtration, you have to give the color of the filtrate and the color of the residue. If the filtrate is colorless then you have to suspect the presence of the cations that are not coloured.

At times in examinations, students might be asked to heat the sample so you have to teach the students the effect of heat on compounds. Some compounds, when heated, they sublime so you have to start suspecting ammonium ions. Some of the compounds, when you heat will observe a color change and when you leave them to cool down, another color shows up. Students have to know all these before they enter the examination hall. That is all the lesson on the identification of cations and anions.

Other approaches to QA though not common they can be used to enrich students' scientific understanding of QA concepts. According to John (an experienced teacher),

We also have the GRID method, used for cation and anion analysis. With that one, you will be told, that the sample contains A, B, C, D, etc. In that order, you are not allowed to use dilute sodium hydroxide to try and test whether the sample contains a gelatinous precipitate or not. After the test you can take the sample and add the appropriate reagents, just to be sure that your inference is correct. For instance, if sample A is $CuSO_{4,}$ you can go behind and quietly add the reagent to see if you will get a light blue gelatinous precipitate or a different answer so that if you made a mistake, you can quickly go through and correct your mistake.

For the GRID method, we use solubility rules. If I mix my solution A and solution B and they all react, now is one soluble and the other insoluble? If all my products are soluble, then I will not see anything. That is where the inference, no visible reaction observed started from since in this method you do not know what you are expecting. that is why, the inference, no visible reaction observed was permitted. There might be a reaction but you are not seeing it.

For the other method, once you add your reagents, you might observe a precipitate, so there is no reason for you to infer: that no visible reaction was observed. For the GRID method, you are going to do permutations, so it is advisable to use one as a sample and the other as the test solution. Assuming you were giving $CuSO_4$ as one of your samples, you have to put $CuSO_4$ as the heading as the test solution then you add the other substance to it. Let's assume, one of the substances is dilute $NaOH_{(aq)}$ you add it to aqueous $CuSO_{4.}$ Your resulting solutions will be $Cu(OH)_2$ and $Na_2SO_{4.}$ Then you use the solubility rule, which is Na_2SO_4 soluble, yes, it is soluble because all sulphates are insoluble unless they combine with group one metals. $CuSO_4$ is not soluble, against that equation, we are going to write blue because the copper sulphate solution is blue. Therefore, you write that against all the solutions that you observed such as, was it blue gelatinous precipitate? did it dissolve in excess or not? The table must be filled vertically and your identification must also be vertical and so if you take copper sulphate. Look at all the columns that you have under which column do I have, that information I have against copper sulphate? So, the ones that I have against them is it sample B, C or D. Then sample A is copper sulphate. If you do not write the equations, you will get confused about what to write. At times, some of the equations will give us gas. Given the table, there is no way to identify gas and you do not have the practical knowledge of what would have happened or what took place, that is why we call it the grid method.

We need to include a flame test for the cations. Some cations, have color when you put them in a flame. The flame test is also important; they do not ask of it often but they can ask a question on it in the theory aspect or objectives. So that is what qualitative analysis of cations and anions is all about. (These views on general pedagogy and subject matter knowledge on QA were shared by John, a teacher with 26 years of teaching experience from Grade B school).

Introduction to a lesson where the teacher revises with students the pre-requisite concepts for the day's QA. There and then teacher demonstrates to students how to carry out QA as a guide for students to follow up. According to Lizzy (a novice teacher),

In order for the students to get the concept well whenever I am teaching qualitative analysis, I involve the students since this is a practical topic. I do some demonstrations and then let them practice by themselves as I guide them in groups. I do so because we do not have enough apparatus to get a set-up for each student.

I revise small aspects of some topics that are relevant to QA such as acids, bases and salts, solubility, and periodic chemistry. I also explain the words gelatinous ppt and chalky ppt. This serves as the foundation for the main topic QA; which is about the identification of cations and anions from a compound.

Development of concept, where teacher guides students accept that there are two categories of QA (inorganic and organic) and that there is to be identified (in particular inorganic QA). According to Lizzy (a novice teacher),

Making students understand that QA can be categorized into two is very important, which are: Inorganic qualitative analysis and organic qualitative analysis.

With the inorganic part cations and anions have to be identified. The cations can be elaborated as Pb^{2+}, Al^{3+}, Ca^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, Zn^{2+}. *Whereas the anions to be identified include* CO_3^{2-}, S^{2-}, NO_3^-, SO_3^{2-}, Cl^-, Br^-, I^-. *Small exposition on the stages in QA has to be given to students such as*

Preliminary test, test for cations, anions and confirmatory test, also flame test and effect of heat on substances has to be looked at critically.

Normally, a small amount of the sample is dissolved in $2cm^3$ *of distilled water to check for its solubility*.

The preliminary test is all about the observation of the sample, especially its color. With a test for cations, the reagents that will be used are dilute sodium hydroxide and dilute ammonia, whilst hydrochloric acid and sulphuric acid, and others are used for a confirmatory test. The flame test also involves dipping a platinum wire into a little concentrated HCl and then holding it at the base of the Bunsen burner flame and then observation is made.

The effect of heat on substances involves heating some of the dry chemicals such as $CaCO_3$, *a carbon dioxide gas that will evolve due to decomposition of the substance to CaO and* CO_2. *The effect of heat causes substances that are not stable to decompose, liberating a gas as well.*

Throughout the tuition of QA, any test, observation, and inference made should be recorded in a table with three columns such as test, observation, and inference which is the actual cation or anion detected. The gases are also smelled by wafting them towards the nose, of which the gas should be 20cm away from the nose.

To detect cations; Pb^{2+}, Al^{3+}, *and* Zn^{2+} *are soluble in excess dilute sodium hydroxide, and* Cu^{2+} *and* Zn^{2+} *are soluble in excess dilute ammonia.* Ca^{2+}, Cu^{2+}, *and* Fe^{2+} *are insoluble in excess dilute sodium hydroxide whilst* Pb^{2+}, Al^{3+}, *and* Fe^{3+} *are insoluble in excess dilute ammonia.*

As you make the students observe, let them note the various colors that depict the presence of each cation and its precipitate; such as Pb^{2+} *white chalky ppt,* Al^{3+} *white gelatinous ppt,* Ca^{2+} *white chalky ppt,* Cu^{2+} *light blue gelatinous ppt,* Fe^{2+} *green gelatinous ppt,* Fe^{3+} *rusty brown gelatinous ppt, and* Zn^{2+} *white gelatinous ppt.*

It can be observed from the general pedagogy and subject matter knowledge of John and Lizzy that experienced is worthy in teaching QA concepts to senior high school students. The experienced teacher is able to sequence the teaching so well that an observer will want to observe his practical lessons. It is, also evident that the novice teacher still has somethings to learn though the subject matter knowledge cannot be in doubt.

There were further interviews we had with teachers having interacted with one experienced and one novice teacher. From these interviews, it was revealed that teaching QA to students only becomes difficult as the instructional approach to teaching it is not clearly spelled out in the chemistry syllabus. An excerpt from the interviews is:

The subject matter is clear except that we do not seem to have a particular procedure to teach it. This is because the syllabus does not spell out a particular procedure as to how to teach it but you understand what is there except that you need to devise your own methods of teaching (Sam, a Teacher).

Teachers' choices of instructional approach in teaching QA are very important to effective teaching of the concept. Per the nature of the QA, it presupposes that the participatory teaching and learning approach (MoE, 2010) is effective for teaching it to students. For some of the teachers, it is because of the scarcity of the equipment and reagents that necessitate the use of demonstration in teaching. Excerpts to justify this assertion are:

I do demonstration most of the time for those compounds that are not available for students to have their hands-on practical work (Anthony, a Teacher).

I do a demonstration when I have limited equipment and chemicals (Baba, a Teacher).

The demonstration approach is further used in teaching QA when teachers have the feeling that the chemicals involved could pose danger to the students, something which is doubtful as the content of the curriculum is carefully selected. An excerpt is:

I use demonstration whenever the chemicals to be used are very dangerous to my students (Baba, a Teacher).

Teachers use the demonstration approach in teaching QA whenever the concept is first introduced to students. Excerpts are:

I use the demonstration method if I am introducing the topic so that students know what is expected of them for the first time (John, a Teacher).

I use demonstration especially when the experiment is new and when the students have not done it before. I sometimes demonstrate it before I allow them to do it (Justice, a Teacher).

The true nature of practical work is when the teacher adopts an instructional strategy that is individual-based, allowing for a direct hands-on activity. This enhances students' development of practical skills. Excerpts are:

The best is the individual hands-on practical work where students develop the needed skills of manipulating the equipment and reagents (John, a Teacher).

Students are always happy when they are involved in one-on-one practical work where they show their results and take pride in them (Sam, a Teacher).

The individual-based activity approach is an important feature of practical work but is missing in schools. The reason for this was shared by Mike:

There are times when we do the hands-on activities, but the class size is always a hindrance … (a Teacher).

There is a need to explain that, apart from the individual-based hands-on activities, there are also group-based hands-on activities. From our observations in the schools, the capacity of most schools' laboratories cannot accommodate all the students at a sitting during practical work. In most of the schools, teachers used group activities which were hands-on. After an observed lesson, Justice explained that:

… I used more group activities because the laboratory cannot contain all the students and we do not even have most of the materials and equipment for individualized learning (a Teacher).

The group hands-on work during practical work is preferred to individual hands-on work. This is because students are actively involved in group hands-on practical lessons. An excerpt is:

This is where I have a problem! When we get to the laboratory, I am very strict. But you will still get several students who would not take part in the practical (Anthony, a Teacher).

Sometimes not all laboratory activities and the practical lessons offer students the opportunity to have hands-on experience. Because the laboratory may not have been well-structured to offer students that opportunity. An excerpt is:

Sometimes, I take them to the laboratory and they practice by themselves but this does not help to improve the situation. It depends on how you the teacher you will organize the practical work (Coffie, a Teacher).

The most dominantly used instructional strategy by teachers is a cooperative learning approach where the teacher groups students depending on the grade of the school and the materials available for students' use. The main reasons assigned for cooperative lessons though not sound grant students the opportunity to benefit from cooperative learning approaches. The excerpts to justify this assertion are:

Yes, I do a lot of group activities because of the lack of chemicals and space for students to work. The scarcity of resources in our laboratories mostly makes us teach it in small groups whenever they come to the laboratory for practical work (Max, a Teacher).

Sometimes you need to manage the chemicals, glassware, and apparatus used. So, if you are to go by the individual, it is either the apparatus will not be enough or chemicals so we go by grouping in 2 or 3 so that it will be easier to teach in groups (Sam, a Teacher).

Cooperative learning approaches are used in practical lessons on QA to provide students with opportunities to interact and share ideas among themselves. The excerpts are:

Sometimes they do it in small groups of three or if the class size is large, then they work in groups of five. This offers students the opportunity to learn from their classmates though I wish they learn individually (Anthony, a Teacher).

Yes, I sometimes use group activities because it helps the students to also help each other (Coffie, a Teacher).

Using cooperative learning approaches is a way of dealing with the issue of large class sizes. A notable aspect of teaching practical work was a division of the class due to large class sizes and large groups. The division of the class into small groups enhances hands-on activities during QA lessons.

When it comes to the students doing the practical work, I divide my class into two. One group will be doing the activities whilst the other group will be observing and after that, they change roles (Mike, a Teacher).

I divide them into groups, one group comes for their practical lesson and I arrange a scheduled class to take the other half of the class through the practical work. In the other group, I give them the assignment to engage them while I take the first group through the practical work. This gives small numbers in groups to exchange roles (Sam, a Teacher).

A challenge with the cooperative learning is that some students do not actively participate in the practical work. For instance, Mike shared that:

Everybody does the practical work. However, if you put them into groups, only a few students will do the activity, the rest will be hiding and pretending to be working when they see you coming. Due to that, I do not like group work. I prefer individual work but the large class size is forcing me to go through the group work method which does not bring out the best in students (a Teacher).

The cooperative learning approaches and the large class size need time to achieve maximum interactions and learning. Teachers do their best to manage the situation in the interest of students. An excerpt is:

You have to manage so that they can perform the activities within the time in their groups. At least there should be two students to a setup. The next group in the class should be given the assignment to engage them (Ben, a Teacher).

Our observations show that indeed teachers use the cooperative approaches more often than the other approaches. This was as a result of the large class size in the schools in relation to the size of the laboratories and materials and equipment available. Students exchanged roles and shared ideas as they performed the practical work on QA concepts. There were instances where students moved from their groups to make inquiries from another group. Teachers seemed relaxed and once in a while moved from group to group to monitor activities in the groups. There was no school where individualized hands-on activities were the approach to teaching QA to students.

This current study has shown that the content in QA is not too difficult to teach the concepts used in QA but the concept and content are difficult for students to learn. The study has added to the literature that the syllabus posed a major difficulty for teachers, especially novice teachers who will require an experienced teacher in tutoring since the syllabus does not provide a clear guideline on how to teach QA. With the required teacher knowledge of the pedagogy and content, the context of the school influences how effectively the teacher will teach QA to students. There is a strong relationship between concepts taught in QA and time as a resource. Teachers use extra time on Saturday and Sunday to help cover the concept of QA. Because schools do not have time allocations for practical work and the worst case is having four periods instead of six (MoE, 2010). The use of extra time to teach QA to students is attributed to the large class size in the selected schools. Magnusson et al. (1999) idea of subject-specific and topic-specific instruction approaches seems to be understood by teachers as most are focusing on the topic-specific. However, per the nature of the practical work, it is always topic-specific as demonstrated by the instructional strategies that most teachers employ in teaching QA concepts such as demonstration, hands-on activities, and cooperative learning. Teachers' preference for cooperative approaches is a result of large class sizes and inadequacy of materials and equipment. However, this approach offers students the opportunity to interact among themselves. The only shortfall is that it demands extra working hours and class management from teachers. Though teachers use some instructional approaches participatory teaching and learning approaches are recommended for teaching chemistry concepts including QA (Adu-Gyamfi et al., 2020; MoE, 2010), and this is contrary to the findings of Treagust et al. (2004) where no particular instructional approaches have been selected for teaching QA concepts. Even in this current study teachers are not aware that participatory learning approaches are recommended by the planners of the curriculum. In the MoE (2010), the teacher and learner activities suggest the instructional approaches to teachers and that teachers are unable to implement or perhaps are ignorant of them. The curriculum contains sufficient information to aid the effective teaching of QA to students (Kaufmann et al., 2002).

The results have shown how teachers use their general pedagogy coupled with their subject matter knowledge of QA and context to enhance their teaching. Thus how teachers teach QA concepts to students in the high school could be a revelation as there could be issues with how teachers prepare to teach and how they implement their intentions in the classroom, further research could be important here. It must be noted that teachers are presumed to possess the knowledge as a result of his/her training as a chemistry teacher. Shulman (1986; 1987) developed three main features of PCK; a component of content, pedagogy, and context, which are the knowledge the teacher possesses in teaching a topic, the instructional methods of teaching, and how students learn the topic. This means that, for teachers to teach QA effectively, they must have a sound understanding of the content, pedagogy, and context. The Inspectorate Unit and the National Council for Curriculum and Assessment should study trends of teachers enacting the chemistry curriculum and if need be, organize professional development programs to take care of any shortfalls of teachers instructing QA concepts to students in the senior high schools. Through the professional development programs teachers could appreciate and understand how the content areas of acids, bases, and salts; solubility; complex ion formation; and precipitation, amphoteric, and addition of acids are structured and organized in the senior high school chemistry curriculum. Teacher’s ability to see through the curriculum and to organize those content areas using the appropriate instructional strategies will help students maximize learning (Wiesen, 2020) in a short space of time.

In this research we studied the general pedagogy and subject matter knowledge of teachers in relation to teaching content of QA concepts in the context of the curriculum and school environment. There were 10 teachers who granted us the audience to study this phenomenon of teaching QA concepts to senior high school students, with one experienced teacher and one novice teacher sharing their general pedagogy and subject matter knowledge of QA concepts. Based on the findings it can be said that teachers’ general pedagogy and subject matter knowledge in the right context combine to influence effective teaching of QA concepts to senior high school students. It is, therefore noteworthy of educators and researchers in chemistry take advantage of any theory linking pedagogy, content, and context to further investigate how context influences teacher pedagogy and the content of chemistry.

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