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Exploring the Teaching and Learning of Qualitative Analysis in Ghanaian Senior High Schools

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ABSTRACT
This qualitative study investigates the instructional practices and learning outcomes of qualitative analysis in Ghanaian senior high schools. Data was collected through classroom observations, teacher and learner interviews. The schools' profiles and infrastructure revealed varying levels of resources, with School X having non-functional laboratory equipment, School Y lacking a functional science laboratory, and School Z boasting six well-equipped science laboratories. Non-participant classroom lesson observations were conducted to garner authentic insights into the teaching and learning of qualitative analysis. A total of 16 lessons were observed, followed by debriefing sessions with teachers to clarify instructional practices. The study aimed to explore the enacted chemistry curriculum in relation to the intended curriculum, shedding light on the challenges and opportunities faced by teachers and learners. The findings provide valuable implications for teacher education, professional development, and chemistry education policy in Ghana. By understanding the complexities of teaching and learning qualitative analysis, educators and policymakers can develop targeted interventions to improve student learning outcomes in science education.

Keywords: qualitative analysis, chemistry education, teacher practices, learner outcomes, Ghanaian senior high schools.

INTRODUCTION

The concept of chemical qualitative analysis poses a significant pedagogical hurdle for high school students globally, with a plethora of studies indicating widespread difficulties in grasping this fundamental concept (Shamsulbahri & Zulkiply, 2021). This phenomenon is particularly noticeable among senior secondary students in diverse educational contexts, including Nigeria, Gambia, Sierra Leone, Singapore, and Malaysia, who consistently struggle to demonstrate proficiency in qualitative analysis-related questions (Lay & Osman, 2018; Shamsulbahri & Zulkiply, 2021; WAEC, 2018, 2019). The ubiquity of this challenge across different cultural and educational landscapes warrants an exploration of the underlying factors contributing to this pedagogical impasse, highlighting the need for innovative instructional strategies to enhance student comprehension and mastery of chemical qualitative analysis.

The struggle to master chemical qualitative analysis is a pervasive phenomenon among elective chemistry students in Ghanaian senior high schools, as evidenced by a growing body of research (Adu-Gyamfi et al., 2024; Anim-Eduful & Adu-Gyamfi, 2022; Hanson, 2015). Furthermore, a longitudinal analysis of Chief Examiners' reports from the West African Examination Council (WAEC) reveals a consistent pattern of underperformance among Ghanaian students in the West Africa Senior Secondary Certificate Examinations (WASSCE), particularly in questions related to qualitative analysis (WAEC, 2018-2020). The Chief Examiners' reports from

the West African Examination Council (WAEC) have consistently highlighted a number of conceptual misconceptions and procedural errors among students in chemical qualitative analysis, emphasizing a lack of understanding of fundamental concepts (WAEC, 2019; 2020). Notably, students' struggles extend beyond mere procedural knowledge, as they often fail to make accurate observations, and draw appropriate inferences, revealing a deeper cognitive dissonance.

The incorporation of qualitative analysis into the secondary school chemistry curriculum is predicated on the notion that it will foster skills, knowledge, and positive attitudes towards chemistry, science, and technology (Abungu et al., 2014). However, the persistent underperformance of students in this domain raises fundamental questions about the efficacy of pedagogical practices and the quality of teaching and learning. This highlights a critical disconnection between curricular intentions and student outcomes, stressing the need for an examination of the pedagogical, cognitive, and contextual factors contributing to this phenomenon. By interrogating this disconnect, researchers and educators can collaboratively develop evidence-based strategies to enhance the teaching and learning of qualitative analysis, thereby promoting a more inclusive and effective science education.

A significant body of research has consistently highlighted the challenges high school students face in grasping qualitative analysis concepts. This knowledge gap presents a critical opportunity for scholarly inquiry, as unpacking the reasons behind student difficulties can inform the development of targeted pedagogical interventions, ultimately enhancing the teaching and learning of qualitative analysis and fostering a deeper understanding of chemistry concepts.

Despite the critical importance of qualitative analysis in chemistry education, research on effective teaching and learning strategies remains scarce. However, recent studies have begun to shed light on promising pedagogical approaches. Notably, Shamsulbahri and Zulkiply's (2021) investigation into the impact of Directed Activity Related to Text (DART) on Malaysian secondary school students' achievement in qualitative analysis revealed significant enhancements in student learning. Similarly, Akkuzu and Uyulgan's (2017) study in Turkey demonstrated the efficacy of the I diagram within a Guided Inquiry Learning Approach (GILA) in fostering improved achievement, knowledge structuring, and scientific explanation skills among university students in Analytical Chemistry Laboratory. These pioneering studies underscore the potential of innovative pedagogical strategies to revolutionize the teaching and learning of qualitative analysis, justifying further exploration to inform evidence-based practices in chemistry education.

While existing research has predominantly focused on instructional strategies for teaching qualitative analysis (Akkuzu & Uyulgan, 2017; Shamsulbahri & Zulkiply, 2021), an understanding of the interplay between teacher characteristics, student factors, school climate, and instructional materials remains elusive. Syahabuddin et al. (2020) contend that teacher deficiencies may underlie student struggles, while Motegi and Oikawa (2019), Obonyo et al. (2018), and Nilsen et al. (2016) emphasize the influence of student characteristics, school climate, and instructional materials on educational outcomes. This study seeks to bridge the knowledge gap by examining

the complex interrelationships between these factors and their impact on student understanding of qualitative analysis, ultimately informing a more comprehensive and effective pedagogical approach.

The pivotal role of qualitative analysis in the chemistry curriculum, as a cornerstone of formal assessments in public examinations (Shamsulbahri & Zulkiply, 2021) and a foundational precursor to advanced disciplines such as forensic chemistry, pharmaceutical chemistry, and drug technology, highlights the necessity for a rigorous and comprehensive investigation into its pedagogy at the senior high school level. This study seeks to explore the underlying issues and complexities surrounding the teaching and learning of qualitative analysis, with a view to informing evidence-based practices that can enhance student understanding, improve educational outcomes, and foster a more robust foundation for future scientific inquiry and professional applications. By interrogating the pedagogical dynamics of this critical topic, this research aims to contribute meaningfully to the ongoing quest for excellence in chemistry education.

Literature review

Qualitative analysis stands as a crucial yet intricate facet of analytical chemistry (Pomerantsev & Rodionova, 2021). The definition of qualitative analysis, however, varies among scholars. Trullols et al. (2004) describe it as a technique for determining the presence of specific species within a sample. Conversely, Lendl and Karlberg (2005) define it as a branch of analytical chemistry focused on detecting and identifying one or more constituents of a sample, ultimately yielding a binary response. In this study, qualitative analysis is operationally defined as an analytical method aimed at identifying species such as atoms, ions, compounds, or functional groups within an analyte (Lambert, 2020). This method is applicable to both organic and inorganic substances. Unlike quantitative analysis, which measures the amount of a substance, qualitative analysis is concerned with attributes such as color, atomic structure, odor, electrical conductivity, and texture (Case Chemicals, 2016). It produces dichotomous results, indicating the presence or absence of a species in a sample (Lim et al., 2020). This technique often requires specific instruments or laboratory equipment to detect and identify chemical components in unknown samples (Cuadros-Rodríguez et al., 2016).

Qualitative analysis has been instrumental in numerous significant discoveries and plays a crucial role in various aspects of daily life (Urban, 2016). Its applications are diverse and impactful: medical professionals utilize qualitative analysis to diagnose ailments; sports teams and regulatory bodies employ it to detect doping among athletes; environmental technicians analyze water samples to identify elements such as barium, mercury, or arsenic; law enforcement agencies at airports and harbors conduct preliminary investigations of suspicious materials using qualitative analysis; and forensic scientists rely on it to gather and preserve crime scene evidence (Cuadros-Rodríguez et al., 2016; Lambert, 2020). Furthermore, qualitative analysis is integral to the routine operations of chemists in industries such as food, mining, and pharmaceuticals (Rodionova et al., 2019).

Given its significance, qualitative analysis has become a cornerstone of chemistry curricula, laying the groundwork for advanced studies in fields such as forensic chemistry, pharmaceutical chemistry, drug development, and medical laboratory technology. Moreover, qualitative analysis is essential in high school elective chemistry final exams across many countries, prominently featured in assessments like the Cambridge IGCSE and WASSCE (CAIE, 2017a; WAEC 2018, 2019, 2020, 2021). Despite its importance, high school students often find qualitative analysis challenging to grasp (Lay & Osman, 2018). Reports from elective chemistry chief examiners have consistently highlighted numerous misconceptions held by students in qualitative analysis experiments (WAEC, 2017, 2018, 2020).

Conceptual framework

The quest to enhance high school students' comprehension of qualitative analysis in chemistry has become a pressing concern in science education. Constructivism, a revolutionary theory of knowledge acquisition, offers a promising solution. By empowering learners to become active architects of their own understanding, constructivism transforms the learning process from a passive reception of information to an engaged and dynamic construction of knowledge (Clark, 2018). This study capitalizes on the transformative potential of constructivism to foster a deeper, more personalized understanding of qualitative analysis among high school chemistry students. By centering learners in the knowledge construction process, this research aims to leverage the complex interplay between context, teacher facilitation, and student agency to enrich the learning experience (Bada & Olusegun, 2015; Fernando & Marikar, 2017). Building on the philosophical foundations laid by Socrates, Plato, and Aristotle, and later shaped by Piaget, Bruner, and Vygotsky, this study seeks to harness the power of constructivism to enhance the teaching and learning of qualitative analysis in high school chemistry, aligning with the theory's proven potential to revolutionize science education.

METHOD

This qualitative study drew on data from classroom observations, teacher and learner interviews, conducted across three senior high schools in Ghana, representing distinct geographical zones. Pseudonymized as "School X," "School Y," and "School Z," these government schools were selected to ensure regional representation. Following approvals from District Directors of Education and headteachers, informed consent was obtained from participating teachers ("Sir Alex," "Sir Ben," and "Sir Courage") and final-year science students.

School X: Profile and Infrastructure

Established in 1976, School X has a learner population of 2345 and 139 teachers, including 24 science teachers, with four specialized in elective chemistry. The school's science department consists of 19 classes across three year groups (7-7-5) and three functional laboratories, each assigned to a specific science discipline (chemistry, biology, and physics). However, the laboratories' equipment, including desktop computers, was non-functional during data collection. Notably, most chemistry test reagents had expired.

School Y: Profile and Infrastructure

In contrast, School Y (established, but year not specified) is a Category C school with 1234 learners and 53 teachers, including 12 science teachers, three of whom specialize in chemistry. The school lacks a functional science laboratory, relying on a small storage room for science equipment.

School Z: Profile and Infrastructure

School Z, established in 1960, is a Category A institution with 3683 learners and 195 teachers, including 48 science teachers, eight of whom specialize in chemistry. The school boasts six science laboratories, with two dedicated to chemistry, each with an attached prep room. The learner population is predominantly boarders.

These contextual details provide essential background information for understanding the research findings.

To garner authentic insights into the teaching and learning of qualitative analysis in Ghanaian senior high schools, this study employed non-participant classroom lesson observations. This method enabled a comparative analysis of the intended chemistry curriculum and its enacted counterpart in the classroom. Across three schools (X, Y, and Z), a total of 16 lessons were observed, with six lessons in Schools X and Y, and four in School Z. Each 2-hour lesson was followed by a 15-minute debriefing session with the respective teacher to clarify observed instructional practices.

RESULTS AND DISCUSSION

Case Study: Sir Ben's Qualitative Analysis Lessons

This section examines the instructional context of Sir Ben's qualitative analysis lessons, conducted in the SHS 3 science classroom. The class comprised 32 learners (19 males, 13 females), with an attendance rate exceeding 98% across the six observed lessons. Notably, all learners were boarders, potentially influencing their academic engagement and motivation. The physical learning environment presented some challenges. The relatively small classroom accommodated a sizable student body, creating a crowded atmosphere conducive to potential distractions. Furthermore, inadequate ventilation and insufficient lighting (with three out of four bulbs non-functional) may have impacted learners' comfort and focus. These contextual factors – high attendance, boarding school setting, and less-than-optimal classroom conditions – provide essential background information for understanding the instructional dynamics and learner outcomes observed in Sir Ben's qualitative analysis lessons.

An analysis of Sir Ben's instructional practices revealed a consistent emphasis on hands-on learning and curriculum alignment. Prior to each of the six observed qualitative analysis lessons, Sir Ben meticulously prepared and brought essential teaching and learning materials, including bench reagents, unknown samples, test tubes, droppers, and boiling tubes. Additionally, he referenced a personal practical chemistry textbook throughout the lessons. Although Sir Ben did not utilize formal, documented lesson plans, the ions addressed in his lessons aligned with the national chemistry curriculum. Moreover, observational data indicated that his teaching and

learning activities closely reflected the curriculum's qualitative analysis standards. This suggests that Sir Ben employed an intuitive, experiential approach to lesson planning, leveraging his subject matter expertise to guide instructional decisions.

Sir Ben's approach highlights the tension between structured lesson planning and flexible, expertise-driven instruction. This case study invites further exploration of the relationships between teacher planning, curriculum alignment, and effective pedagogy in senior high school chemistry education. Sir Ben's teaching methodology in his qualitative analysis lessons exhibited a mix of traditional and interactive approaches. Notably, he did not explicitly connect the new topic to learners' prior knowledge of acid-base reactions, solubility, and redox reactions. Instead, he initiated the first lesson with an open-ended question, leveraging learners' existing knowledge to introduce the concept.

The initial three lessons primarily employed lectures with limited demonstrations and questioning opportunities. Sir Ben conducted experiments, while learners observed and discussed corresponding observations. However, in lessons four to six, the instructional approach shifted to drill-and-practice, where learners performed experiments following chalkboard instructions. This change allowed for increased learner engagement and practice. Sir Ben's instructional approach raises important questions about the balance between teacher-centered and learner-centered instruction, the role of prior knowledge activation, and the potential benefits of incorporating more open-ended, inquiry-based learning experiences in senior high school chemistry education. Sir Ben fostered a positive and interactive learning environment, characterized by healthy relationships between himself and learners, as well as among learners. His lessons encouraged active participation, with opportunities for questioning and discussion. Although few learners asked questions, those who did received thoughtful responses from Sir Ben, which were subsequently integrated into the lesson. Notably, both male and female learners contributed to the discussions. The low question-asking rate may be attributed to the perceived abstractness of qualitative analysis, leading to uncertainty about formulating relevant inquiries.

A focus group discussion with six learners from SHS 3 Science C class provided valuable insights into their understanding and experiences with Sir Ben's qualitative analysis lessons. Participants expressed overall satisfaction with Sir Ben's lessons, feeling confident in their ability to answer questions on qualitative analysis. They particularly enjoyed cation analysis experiments and appreciated Sir Ben's demonstrations. However, learners found anion analysis challenging, especially inference and observation interpretation. Despite rating their understanding high, learners demonstrated limitations in explaining reactions and processes underlying qualitative analysis concepts. For instance, they struggled to identify the type of reaction occurring during chloride ion testing and failed to name the complex formed. Learners lamented the absence of functional laboratories, equipment, and resources, hindering effective teaching and learning. They highlighted challenges such as: Inadequate glassware and chemical reagents, limited access to distilled water, irregular electricity supply, insufficient and library resources. Rote learning and

group discussions were the predominant learning strategies among participants. Some learners employed acronyms to aid memory. Despite claiming mastery over topics like periodicity, acid-base reactions, and redox reactions, learners failed to connect these concepts to qualitative analysis. Participants described healthy relationships among learners and between Sir Ben and learners. This study highlights the need for improved infrastructure and resources, enhanced conceptual connections and diversified learning strategies. Sir Ben, a chemistry teacher with three years of experience, shared his insights on teaching qualitative analysis at School Y. Holding a Bachelor of Education (Science) degree, with a major in chemistry and minor in physics, Sir Ben was pursuing a master's degree in chemistry at the time of the study.

Sir Ben taught both chemistry and integrated science to 145 learners, comprising 65 elective chemistry and 80 integrated science students. Despite enjoying chemistry, Sir Ben felt overwhelmed by the workload, particularly with integrated science, which required preparation in biology, agricultural science, and physics. Sir Ben expressed concern about the lack of professional development opportunities, having never attended a relevant workshop or training session. He welcomed the prospect of participating in such programs to enhance his teaching skills.

Sir Ben emphasized the importance of thorough preparation for qualitative analysis lessons, often borrowing reagents from nearby schools due to inadequate resources. He relied on his familiarity with the curriculum and content, rather than revising textbooks before lessons. Sir Ben aimed to make lessons learner-centered, incorporating demonstrations and drill-and-practice sections to build learners' confidence. Sir Ben identified three key challenges, learners' limited understanding of prerequisite topics (e.g., solubility), inadequate infrastructure (lack of laboratory, reagents, and glassware) as well as insufficient resources. To address these challenges, Sir Ben employed improvisation, motivation, and constant revision of relevant topics. He used the classroom as an improvised laboratory, boiled water with his personal kettle, and motivated learners to work hard despite resource constraints.

Sir Ben described healthy relationships among chemistry teachers but limited interaction with school administrators. He criticized the administrators' lack of support, citing funding constraints as a persistent issue. Sir Ben rated his learners' understanding of chemistry topics as moderate, with varying levels of comprehension.

Case Study: Sir Alex's Qualitative Analysis Lessons

Sir Alex's qualitative analysis lessons were observed in the SHS 3 Science C classroom, with a total enrollment of 53 learners (28 males, 25 females). Notably, attendance rates remained consistently high, averaging 95% across the six lessons. Lessons took place in a well-appointed chemistry laboratory, characterized by, spacious and well-ventilated facilities, mixed-ability grouping, learner-centered seating arrangements and facing the marker board. Despite the conducive learning environment, a notable concern emerged regarding safety protocols. Learners failed to adhere to standard laboratory safety practices, neglecting to wear laboratory coats, safety glasses and gloves during qualitative analysis experiments. This observation highlights the need for enhanced emphasis on laboratory safety protocols, integration

of safety procedures into lesson plans, teacher monitoring and enforcement of safety standards.

Sir Alex demonstrated effective pre-lesson planning by setting up the chemistry laboratory before each class, ensuring a conducive learning environment. The carefully arranged equipment and materials served as essential teaching and learning tools for qualitative analysis. Sir Alex relied on two primary resources, a personalized teaching note, compiled over a decade and a practical chemistry textbook.

He dictated notes from these resources, which learners recorded in their chemistry notebooks. Although Sir Alex did not utilize formal lesson plans, the observed teaching and learning activities aligned with the chemistry curriculum, indicating implicit curriculum mapping. This instructional approach highlights the importance of pre-lesson preparation in creating an effective learning environment. The value of teacher-generated resources in supporting curriculum delivery. The potential benefits of implicit curriculum mapping in promoting flexibility and adaptability. However, the lack of formal lesson plans raises questions about the potential impact on lesson coherence and continuity as well as the challenges of evaluating instructional effectiveness. This instructional strategy warrants further investigation to explore its effects on learner outcomes and teacher professional development.

Sir Alex's teaching approach exhibited several notable characteristics and limitations during the six lessons on qualitative analysis. Sir Alex failed to review and connect prior knowledge (acid-base reactions, solubility, periodicity, and redox reactions) to qualitative analysis, share lesson objectives with learners as well as highlighting the practical applications and importance of qualitative analysis in everyday life. The initial lessons (1-2) were dominated by lecture-based instruction, teacher-led demonstrations and limited opportunities for learner participation. In contrast, lessons 3-6 focused on drill-and-practice exercises, utilizing past Chemistry 2 and 3 questions.

Sir Alex's approach neglected opportunities for learners to discover main ideas through inquiry-based activities, diverse assessment techniques to evaluate learner understanding, integration of concepts across microscopic, symbolic, and macroscopic levels as well as learner autonomy in planning experiments or working individually. This case study highlights the need for curriculum connectivity and contextualization, balanced instructional strategies (lecture, demonstration, inquiry, and practice) and diverse assessment techniques.

Sir Alex's instructional approach revealed limitations in his pedagogical content knowledge (PCK) of qualitative analysis, compromising the effectiveness of his lessons. Sir Alex's explanations lacked depth and failed to elucidate the underlying reasons for observations made during qualitative analysis, provide learners with an understanding of the chemical processes involved. Sir Alex's lessons did not cultivate critical thinking skills among learners, a shortfall attributable to his limited PCK. This omission hindered learners' ability to analyze and interpret qualitative analysis data,

develop problem-solving strategies and integrate theoretical concepts with practical applications.

This case study underscores the importance of robust PCK in enhancing the quality of chemistry instruction. Teachers' content knowledge gaps can compromise learner understanding and retention, restrict the development of critical thinking and problem-solving skills and limit the effectiveness of science education. To address these concerns, educators should prioritize enhancing teachers' PCK through targeted professional development, integrating critical thinking and problem-solving exercises into lesson plans and fostering a learner-centered approach that encourages inquiry and exploration.

Observations of Sir Alex's lessons revealed a positive classroom environment, characterized by harmonious relationships between teacher and learners, collaborative interactions among learners facilitated through group seating arrangements (six learners per group). During drill-and-practice sections, learners engaged in hands-on experiments, promoting active learning. However, notable challenges emerged, these include noisy laboratory environment due to large group sizes, inequitable participation with only a few group members actively performing experiments and limited access to glassware necessitating group work. Interestingly, learners rarely posed questions to the teacher, potentially indicating conceptual clarity with learners grasping explained concepts. In contrast, during group work, learners with prior knowledge of qualitative analysis took on leadership roles, facilitating peer-to-peer discussion and knowledge sharing.

This study highlights the importance of fostering collaborative learning environments, challenges associated with managing large group sizes and limited resources, the value of peer-to-peer learning and knowledge sharing and the need for teachers to monitor learner engagement and understanding. To optimize learner outcomes, educators should consider strategies for promoting equitable participation in group work and encouraging learner inquiry and questioning as well as differentiated instruction to address diverse learner needs.

This study explored learners' experiences and understanding of qualitative analysis through focus group discussions and interviews with six learners (Learner A1-A6) and their teacher, Sir Alex. Learners generally expressed satisfaction with Sir Alex's teaching methods, citing opportunities for hands-on experiments and practice. However, they acknowledged limited understanding of underlying chemical reactions, rote memorization of observations and inferences and difficulty linking qualitative analysis to other chemistry topics.

Sir Alex identified inadequate resources (glassware, reagents, and funding), limited professional development opportunities, high learner-to-teacher ratio as significant challenges affecting teaching and learning. Learners reported enjoyment of hands-on experiments and appreciation for peer-to-peer learning. Learners demonstrated limited conceptual understanding of qualitative analysis and ability to recall observations and inferences. This study highlights the need for improved resources and funding enhanced teacher professional development and learner-

centered approaches promoting critical thinking and conceptual understanding as well as the integration of qualitative analysis with other chemistry topics.

Case Study: Sir Courage's Qualitative Analysis Lessons

Sir Courage's lessons on qualitative analysis were observed in the SHS 3 Science A classroom, comprising 49 learners (35 males, 14 females). Notably, attendance rates were exceptional, with only one male learner absent during the data collection period. All learners were boarders.

The chemistry laboratory provided a conducive learning environment, characterized by spacious and well-ventilated facilities and learner-centered seating arrangements (stools around laboratory benches). During drill-and-practice sections, learners worked in pairs, promoting collaborative learning and enhanced engagement. However, despite the teacher's exemplary practice of wearing a laboratory coat, notable safety concerns emerged, learners' non-compliance with wearing safety glasses and the absence of gloves during qualitative analysis experiments.

Sir Courage and his laboratory assistant demonstrated exemplary pre-lesson planning by setting up the chemistry laboratory before each lesson and ensuring adequate teaching and learning materials. This case study highlights the importance of pre-lesson preparation in creating a conducive learning environment, effective resource utilization in supporting student learning and the potential limitations of not using personalized lesson plans. Sir Courage's teaching approach exhibited similarities with Sir Alex's, characterized by gaps in curriculum connectivity and contextualization.

Sir Courage failed to review and relate prior knowledge (acid-base reactions, solubility, periodicity, and redox reactions) to qualitative analysis and share lesson objectives with learners as well as highlighting the practical applications and importance of qualitative analysis in everyday life.

Sir Courage's lessons primarily employed lecture methods, demonstrations, questioning and answering techniques. While providing opportunities for practice, the approach lacked depth in conceptual understanding and restricted learner autonomy in experiment design and planning. Sir Courage's approach neglected the integration of ICT tools for microscopic visualization, opportunities for learners to link concepts across microscopic, symbolic, and macroscopic levels and learner-centered experiment design and planning. This case study underscores the need for curriculum connectivity and contextualization, balanced instructional strategies (lecture, demonstration, inquiry, and practice), learner-centered approaches promoting autonomy and critical thinking and the integration of ICT tools to enhance conceptual understanding.

Sir Courage's lessons on qualitative analysis demonstrated satisfactory content knowledge, aligning with the chemistry curriculum requirements. The lessons comprehensively covered all nine cations and eight anions specified in the chemistry curriculum. The presented content was sufficient for learners to achieve competence in the chemistry exams. However, Sir Courage's teaching approach overlooked opportunities to foster connections between qualitative analysis and related concepts

(acid-base reactions, periodicity, bond formation), enhance learners' deeper understanding through cross-conceptual integration.

This case study highlights the importance of robust content knowledge in teaching qualitative analysis, the need for pedagogical strategies that integrate cross-conceptual connections and the potential benefits of interdisciplinary approaches in enhancing learners' conceptual understanding.

Observations of Sir Courage's class revealed a positive and inclusive learning environment, characterized by collaborative interactions and active participation, high levels of engagement during note-taking and explanatory sessions, voluntary participation in question-and-answer sessions and active contribution of observations and inferences during experiments. This case study highlights the importance of establishing a positive classroom climate, effective strategies for promoting learner engagement and participation and benefits of collaborative learning and group work in science education. A focus group discussion involving eight learners from Sir Courage's class provided valuable insights into their understanding and perceptions of qualitative analysis concepts. Participants reported enjoying Sir Courage's lessons due to practical and demonstration-based approaches and opportunities to solve past exam questions.

Learners demonstrated varying levels of understanding, cation analysis was preferred over anion analysis. Ratings of understanding ranged from excellent to satisfactory. Participants struggled to explain underlying reactions and procedures. Despite familiarity with topics like solubility, chemical bonding, and redox reactions, learners failed to connect qualitative analysis concepts to prior knowledge. They had difficulty understanding concepts like intermolecular bonding and buffer solutions.

Sir Courage, a seasoned chemistry educator with 13 years of experience, serves as the unit head of chemistry. Holding a Bachelor of Education (Science) degree with a major in chemistry and minor in biology, he previously taught general science in a junior high school for three years. Sir Courage teaches seven SHS 3 classes, totaling 322 learners, attributing increased enrollment to the free SHS policy. Despite acknowledging benefits, he expresses concerns about inadequate resources, particularly chemistry teachers.

Sir Courage participated in five professional development sessions, with only one focused on chemistry. He prepares thoroughly for lessons, reviewing textbooks and notes, but rarely consults the chemistry curriculum. Sir Courage employs lecture and demonstration methods, emphasizing practice for learner retention. However, he faces challenges including inadequate glassware and chemical reagents, expired reagents, heavy workload and unstable internet connectivity.

Discussion

The demographic analysis of the surveyed chemistry teachers revealed a predominantly experienced cohort, with over 75% possessing six or more years of teaching experience. This finding aligns with Ajayi's (2017) classification of experienced chemistry teachers. Notably, the teaching experience of the observed teachers mirrored this trend, with two of the three teachers boasting over a decade of experience, while Sir Ben had three years of experience at the time of data collection.

Interestingly, this study's findings challenge the widely-held assumption that teaching experience directly correlates with effectiveness (Podolsky et al., 2019;). Contrary to Podolsky et al.'s (2019) assertion that years of experience significantly influence teacher effectiveness, the case studies revealed that Sir Ben's lesson presentations and activities were comparable in quality to those of his more experienced counterparts, Sir Alex and Sir Courage, who had 19 and 13 years of experience, respectively. Moreover, despite varying levels of experience, all three teachers employed similar instructional strategies and lesson preparations. This outcome supports Graham et al.'s (2020) contention that teaching experience does not necessarily determine the quality of lessons delivered. These findings contribute to the ongoing debate surrounding the relationship between teaching experience and effectiveness, highlighting the need for further investigation into the complex factors influencing teacher performance.

The case studies revealed a striking discrepancy between teachers' self-reported mastery of qualitative analysis concepts and the actual instructional practices observed. Notably, the content knowledge of two of the three teachers, Sir Ben and Sir Courage, was found to be satisfactory, whereas Sir Alex's content knowledge was significantly lacking. This finding resonates with existing literature, which consistently highlights the pervasive issue of inadequate teacher content knowledge (Hirpa et al., 2024; Jordan et al., 2018; Asl et al., 2014; Moats, 2014). The implications of this phenomenon are profound, as research has established a strong correlation between teachers' content knowledge and student learning outcomes.

An analysis of Sir Alex's instructional practices revealed specific pedagogical shortcomings. For instance, he failed to provide learners with essential conceptual frameworks. These instructional gaps cannot be dismissed as isolated incidents, as they persisted across all six observed lessons. The persistence of these content knowledge gaps supports the "Peter Effect" hypothesis (Jordan et al., 2018), which posits that teachers cannot impart knowledge they themselves lack. This study's findings underscore the urgent need for targeted professional development initiatives to enhance teachers' content knowledge and, by extension, improve student learning outcomes in chemistry education.

A striking anomaly emerged from the comparative analysis of Sir Alex and Sir Ben's content knowledge of qualitative analysis, despite their vastly differing levels of teaching experience. Sir Ben, with only three years of experience, demonstrated superior content knowledge compared to Sir Alex, who had amassed 19 years of teaching experience. This finding challenges the conventional wisdom posited by Jordan et al. (2018), which suggests that teaching experience directly enhances content knowledge.

Conversely, our study's outcome aligns with Asl et al.'s (2014) counterintuitive assertion that teachers' content knowledge may actually deteriorate with increased years of service. This phenomenon can be attributed to the potential for complacency among veteran teachers, leading to inadequate lesson preparation and a diminished commitment to ongoing professional development (Hirpa et al., 2024). The

implications of this finding are profound, suggesting that experience alone is no guarantee of expertise.

However, research suggests that veteran teachers can leverage their experience to enhance student learning outcomes if they prioritize thorough lesson preparation and engage actively in professional development opportunities (Hirpa et al., 2024; Asl et al., 2014). This study's findings underscore the need for educators to recognize the potential pitfalls of complacency and proactively seek opportunities for growth and renewal throughout their careers.

CONCLUSION

In conclusion, the persistent difficulties high school students face in understanding qualitative analysis underscore the need for a comprehensive investigation into the multifaceted factors influencing this issue. This qualitative study provided an in-depth examination of the teaching and learning of qualitative analysis in Ghanaian senior high schools. The findings highlighted the complexities and challenges faced by teachers and learners in navigating the chemistry curriculum, despite varying levels of school resources. Notably, the study revealed discrepancies between the intended and enacted chemistry curriculum, with teachers' instructional practices often influenced by contextual factors such as laboratory infrastructure and resource availability. The findings also underscored the importance of teacher content knowledge, pedagogical expertise, and ongoing professional development in enhancing student learning outcomes. The study's results have significant implications for chemistry education policy and practice in Ghana. To improve student learning outcomes, educators and policymakers must prioritize the

teacher professional development programs focusing on content knowledge and pedagogical innovation and investment in laboratory infrastructure and resources as well as the contextualized curriculum development aligning with Ghanaian educational contexts. By addressing these areas, Ghanaian senior high schools can foster a more effective and inclusive learning environment for chemistry education.

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