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Research Article

Challenges in Understanding the Mole Concept Among Level 200 Students in Science Colleges of Education in Ghana

Michael Owusu[*], Humphrey Darkeh Assem, Theophilus Aquinas Ossei-Anto, Frank Owusu Ansah

Department of Teacher Education, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Abstract

This study investigates challenges in understanding the mole concept among pre-service teachers in Ghanaian Colleges of Education. Chemistry education is fundamental for fields such as medicine and engineering, yet students often face difficulties due to inadequate foundational knowledge and ineffective teaching methods. The mole concept is crucial for grasping various chemical phenomena, but its complexity frequently results in significant learning challenges. This study employs a mixed-method explanatory design, combining quantitative diagnostic tests and qualitative interviews with 1,211 pre-service teachers from six selected colleges. The study identifies key challenges in learning the mole concept, including difficulties in translating word problems into equations, determining mole ratios, deriving empirical and molecular formulae, and understanding the relationship between stoichiometric coefficients and moles. The analysis categorizes these challenges into comprehension, transformation, process skills, and encoding errors, with process skills and transformation challenges being the most prevalent. Findings reveal that many students struggle to solve problems without formulae, highlighting a lack of conceptual understanding. Interviews with pre-service teachers confirm quantitative data, indicating that students often rely on rote memorization rather than conceptual grasp. The study concludes that improvements in teaching methods are needed, emphasizing the importance of understanding over memorization and recommending small group collaborative learning. Contributions include filling empirical gaps in the literature regarding pre-service teachers' challenges and suggesting practical recommendations for enhancing chemistry education.

Keywords

Mole Concept, Pre-Service Teachers, Chemistry Education, Pedagogical Content Knowledge, Educational Materials, Teaching Methods

1. Introduction

The quality of science education reflects a nation's progress and is essential in fields such as medicine, engineering, telecommunications, agriculture, and pharmacy [43]. Despite its importance, students often struggle with science due to inadequate foundational knowledge and ineffective teaching methods [1]. Chemistry, a core scientific discipline, under-

[*]Corresponding author: stmichaelacademy69@yahoo.com (Michael Owusu)

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pins many fields and requires comprehension at macroscopic, sub-microscopic, and symbolic levels [47].

A thorough understanding of the mole concept is crucial for mastering chemistry. According to the International Union of Pure and Applied Chemistry (IUPAC), a mole is defined as the amount of substance containing as many entities as there are atoms in 0.012 kg of the C-12 isotope [38]. This concept allows chemists to quantify [11] microscopic entities involved in chemical reactions on a macroscopic scale [21, 54]. Mastery of the mole concept is vital for topics like solution concentration and other advanced chemical concepts [29, 56]. However, its complexity often poses significant challenges for students [20, 33].

The purpose of this study is to explore the specific challenges pre-service teachers make when learning and teaching the mole concept, identify the underlying causes of these challenges, and propose strategies to enhance their understanding and instructional practices. By addressing these issues, the study seeks to contribute to the improvement of chemistry education and the development of more effective teaching methodologies that align with constructivist principles.

The objective of this study was to systematically identify and analyze the specific misconceptions and challenges that pre-service teachers encounter in understanding and applying the mole concept in chemistry. Additionally, it seeks to assess the impact of constructivist teaching approaches on enhancing pre-service teachers' comprehension and instructional methods related to the mole concept.

The study was guided by the following questions: Firstly, what are the prevalent misconceptions and challenges demonstrated by pre-service teachers in the learning and instruction of the mole concept in chemistry? Secondly, in what ways do constructivist teaching approaches affect pre-service teachers' comprehension and pedagogical effectiveness related to the mole concept?

The significance of this study is to enhance pre-service teachers' foundational knowledge by identifying and addressing common misconceptions in teaching the mole concept, potentially leading to more effective science education. By developing Pedagogical Content Knowledge (PCK) specific to the mole concept, the study could help tutors make complex chemistry concepts more accessible. Insights from the study may inform teacher training programs, better preparing future educators to tackle challenging topics with confidence. Additionally, the study advocates for evidence-based instructional strategies that promote active learning and critical thinking, benefiting both teachers and students. Ultimately, the findings could influence the development of more effective chemistry curricula and contribute to the broader field of educational research.

1.1. Theories of Knowledge Construction

Constructivism, a prominent learning theory in this study, emerged as a challenge to traditional cognitive development models, emphasizing the importance of students actively constructing their own knowledge rather than passively receiving information. Constructivist learning is characterized by active participation, collaboration, contextual learning, and reflection. It posits that learning is an active process in which students make sense of new information using their prior knowledge and experiences.

1.2. Key Points of Constructivist Learning Theories

1. Active Meaning-Making: Knowledge is constructed through interactions with the world.
2. Cognitive Conflict: Students interpret tasks through challenges or puzzles.
3. Collaboration: Meaning is created through cooperation and engagement in real-world practices.
4. Reflection and Feedback: Understanding is enhanced through reflection and assessment.
5. Student Responsibility: Students take responsibility for their own learning.

1.3. Individual Constructivism

Jean Piaget's individual constructivism emphasizes that students comprehend abstract concepts through cognitive development and prior knowledge. Learning is viewed as a mental activity where students create mental models and adapt them through assimilation and accommodation.

1.4. Social Constructivism

Lev Vygotsky's social constructivism highlights the role of social interactions in learning. It posits that students make sense of new information through community engagement and collaborative problem-solving. Language is a crucial tool for cognitive development, and the "zone of proximal development" is where students learn with the assistance of more knowledgeable individuals.

1.5. Key Takeaways

1. Constructivist learning involves students actively constructing knowledge through their experiences and interactions.
2. Individual constructivism focuses on cognitive development and personal mental models.
3. Social constructivism emphasizes the role of social context and interactions in learning, with language being a key component.
4. Effective teaching should balance student-centered and teacher-directed approaches, leveraging social interactions and scaffolding to support learning.

In summary, constructivist approaches provide a comprehensive framework for teaching and learning, emphasizing active engagement, social interaction, reflective practices, and real-world applications to enhance deep and meaningful learning as seen in Figure 1.

Figure 1. *Students Active roles in constructing meaning [16].*

2. Concept of Mole as Explained in Textbooks

2.1. Defining the Mole Concept in Textbooks and Teaching

Research has highlighted a significant gap between the scientific definition of the mole and its educational portrayal. noted that this discrepancy has been recognized for decades. It has been found that many textbook definitions of the mole are incompatible with the SI definition, with only two out of 28 educators providing the correct SI definition. Students often struggled with varying definitions of the mole, typically associating it with Avogadro's number or mass [54].

Further research examined textbooks from 1976 to 1996 and teachers' views on the mole concept [21]. The study found that textbooks often lacked explicit definitions and historical context, and teachers exhibited varied and sometimes incorrect definitions. About 44.4% of trainee teachers associated the mole with an atomistic sense, while 38.9% associated it with mass. Textbooks frequently used "mole" ambiguously and provided minimal historical context, affecting students' understanding.

30 general chemistry textbooks were analyzed and found that most did not address the historical development of the mole concept or the scientific community's challenges [36]. The textbooks often contained errors, and the mole was incorrectly linked to concepts like chemical mass or Avogadro's number rather than the SI definition. Only a small percentage of textbooks accurately described the mole as a unit of quantity.

This analysis was extended to textbooks from the US, France, and Turkey, identifying grammatical mistakes and instructional difficulties [55]. The study emphasized the need for textbooks and educators to correctly integrate microscopic, macroscopic, and symbolic knowledge levels to enhance understanding of the mole concept.

2.2. Key Findings

1. Textbooks and teachers often present the mole concept inconsistently with the SI definition.
2. Definitions of the mole are frequently ambiguous, leading to confusion among students.
3. Effective teaching requires aligning the mole concept with microscopic, macroscopic, and symbolic levels of chemical knowledge.

2.3. Recommendations

1. Educators and textbook authors should ensure accurate and consistent definitions of the mole.
2. Teaching materials should provide historical context and avoid confusing the mole concept with other quantities like mass or volume.
3. Effective teaching should integrate scientific knowledge with student-friendly explanations and models.

2.4. Pedagogical Content Knowledge (PCK) of the Mole Concept

Research on Pedagogical Content Knowledge (PCK) has explored its development in pre-service teacher education, the impact of Content Knowledge (CK) on topic-specific PCK, and methods for eliciting PCK across different topics. However, studies specifically focusing on the mole concept PCK are limited [5]. Two key studies have been examined [19]. These studies employed advanced rubrics and various data collection methods, including focus groups, surveys, interviews, and classroom observations. The Content Representations (CoRes) and Pedagogical and Professional experience Repertoires (PeP-eRs) are notably popular tools for recording and analyzing PCK.

2.5. Teaching and Learning Strategies

Effective teaching and learning strategies are essential in addressing challenges in understanding the mole concept among pre-service teachers. Learning involves acquiring and processing knowledge at various levels, such as understanding, application, and communication [56]. Students enhance the meaningfulness of new concepts by connecting them to existing frameworks [58]. Constructivist theory, which emphasizes self-regulation, discovery, and analysis, views learning as an adaptive change in behaviour or belief [24, 26]. Effective learning includes active construction, social and individual experiences, and leveraging learner differences [10].

Active learning, including group work, improves information generation and problem-solving skills [3]. Although constructivist principles advocate for student autonomy, teacher involvement remains crucial through scaffolding techniques like questioning [58]. An ideal learning environment is student-centered, knowledge-centered, assessment-centered, and community-centered, promoting behavior change through motivation and conducive settings [7, 30]. Behavior modification involves both individual and societal factors and requires ongoing support [16].

Teaching strategies should match students' needs and course objectives, balancing directed and facilitated learning. Effective teaching adapts to students' cognitive development, employing strategies like guided discussions, group work, and problem-based learning [2]. Understanding complex concepts, like the mole concept in chemistry, requires aligning teaching methods with students' learning preferences, such as intuitive versus sensing styles [3, 1].

Social groups play a significant role in knowledge formation, with social constructivism and sociocultural theory emphasizing the social nature of learning. These theories advocate for knowledge construction through interaction and collaboration [2]. Teachers should use diverse strategies to support collaborative learning and acknowledge the influence of peers, parents, and teachers in shaping understanding [58].

No single instructional method suits all students or subjects; thus, teachers should employ a range of strategies, reflecting on their effectiveness over time [10]. Effective teaching aligns with learning theories and adapts to the context of the lesson [17]. Integrating cognitive and behavioral strategies is essential to address various learning needs [58].

3. Participatory Learning

Participatory learning, which involves collaborative research and practice, is integral in teaching complex concepts like the mole concept. This approach emphasizes integrating local content and promoting student involvement [3, 28]. It involves repetitive, formative review processes and collaboration among educators, researchers, and students, fostering two-way communication and active participation [28, 30].

Reflective practice in participatory learning helps educators make informed decisions based on formative assessments, which are crucial for achieving educational goals despite potentially slowing progress [3, 27]. This approach bridges theory and practice, using diverse strategies and valuing student input [50]. It promotes collaboration, problem-solving, and critical thinking, with facilitators guiding the learning process rather than dominating it [48].

Participatory learning values student engagement, providing opportunities for peer learning, problem-solving, and personalized education. Including parents in the learning process enhances student performance through various interaction modes [32]. Overall, participatory learning supports active participation and critical engagement, leading to better understanding and satisfaction in the learning process [37].

3.1. Cooperative Learning

Cooperative learning is effective in teaching the mole concept in chemistry by engaging students more actively than traditional lectures. It fosters a collaborative, non-competitive environment where students work together toward shared goals, motivating each other through their interdependence [35, 45]. Research shows that cooperative learning positively impacts both academic and social development [34]. Unlike general group work, cooperative learning is carefully structured by teachers to promote effective collaboration, building mutual respect and self-esteem among diverse groups of students [41]. Smaller teams (3-4 members) are particularly beneficial, with effective peer teaching and social support contributing significantly to enhanced learning outcomes [6]. Cooperative learning integrates academic and social skills, making it a valuable pedagogical tool for modern education, where teamwork and interpersonal skills are essential [34, 44].

3.2. Interview Questions for Challenge Classification

To classify challenges in written mathematics or science tasks through student interviews, Newman's procedure delineates a five-step hierarchy for addressing one-step word problems, such as calculating the number of moles required for a chemical reaction as cited in [54]. This hierarchy is instrumental in identifying and categorizing challenges that students make. The steps are:

1) Reading: Ensure the problem is understood by reading it correctly.
2) Comprehension: Accurately interpret the information provided in the problem.
3) Transformation: Translate the problem into a mathematical or scientific strategy.
4) Process Skills: Employ the appropriate methods and procedures to solve the problem.
5) Encoding: Write down the solution correctly.

Challenges occurring at any of these steps can lead to incorrect solutions, even if occasionally correct answers are produced by chance. The Newman hierarchy offers a structured framework for identifying and understanding these error stages, allowing for a systematic approach to error analysis. Despite the linear appearance of the hierarchy, problem solvers may revisit earlier steps as needed [8, 14].

This adaptation of Newman's procedure to the context of error classification in mathematics and science tasks emphasizes the relevance and application of the hierarchy to educational practices.

The study employs a mixed-methods approach, combining qualitative and quantitative data collection. This approach provides a comprehensive understanding of the research problem by integrating interviews (qualitative) with tests and questionnaires (quantitative) [18]. Mixed methods are valued for reducing bias and offering diverse perspectives [46]. Researchers use mixed methods to explore complex phenomena more thoroughly and address methodological biases [10, 52].

The study uses a mixed-method sequential explanatory design. This design first collects and analyzes quantitative data, followed by qualitative data to explain and interpret the quantitative findings [36]. The quantitative phase involves a mole concept diagnostic test (MCDT) to identify common challenges, followed by a questionnaire [40]. In the qualitative phase, one-on-one interviews explore reasons behind the challenges. This design helps in understanding the common challenges made by pre-service teachers in learning the mole concept and devising solutions [53]. Students with varying performance levels on the test were selected for further qualitative analysis to gain deeper insights into their understanding and reasoning.

This study's population comprises six Colleges of Education in Ghana, divided into five zones: E (Ashanti, Brong, and Ahafo Regions), F (Central and Western Regions), G (Eastern and Greater Accra Regions), H (Volta and Oti Regions, and I (Northern Region). Sixteen colleges are affiliated with University A, with only the six offering General Chemistry, reading topics including mole concepts.

Level 200 students from these colleges were included since this topic is taught in the second semester of their second year. As of March 2022, there were 2,347 pre-service teachers, though not all studied Chemistry. The study considered an accessible population of 1,211 pre-service teachers who took Chemistry as an elective. These enrolments were verified by the Academic Affairs offices and chemistry tutors of the selected colleges.

According to studies, a sample can be determined by ensuring it reflects the population's characteristics or using a mathematical formula [32]. The intact class of 1,211 pre-service teachers was selected for the study. The sampling involved three stages:

Stage One: Purposive sampling was used to select six colleges from the 46 in Ghana. These colleges, affiliated with University A, offer chemistry as an elective course, making them suitable for the study. Purposeful sampling targets respondents with relevant experience and traits likely to provide pertinent information [42].

Stage Two: A purposive sampling technique was used to select the level from the various selected colleges. This is because not all the levels in the colleges selected study the mole concept. Hence, they cannot be selected to be part of the study. This enabled the researcher to sample pre-service teachers who are studying chemistry as a subject and learning mole concept as a topic and, therefore, could be in the position to be part of the study.

The results are shown in Table 1.

Table 1. *Number of science colleges that were selected and the number of students sampled.*

ZONE	NAME OF SELECTED COLLEGEOF EDUCATION	NUMBER OF STUDENTS OFFERING GENERAL CHEMISTRY
Ashanti, Brong, and Ahafo	E	288
	F	123
Central and Western	G	269
	H	302
Eastern and Greater Accra	I	217
Volta and Oti	J	12
Total		1211

Source: Colleges' Academic Affairs Offices (2023)

3.3. Instrumentation

The primary research instruments for this study are tests, questionnaires, and interviews.

Mole Concept Diagnostic Test (MCDT)

The Mole Concept Diagnostic Test (MCDT), a standardized test, was used to identify the difficulties students face with the mole concept and propose solutions. This test assesses students' challenges with the concept and offers potential remedies. Each participant's performance was scored, similar to the evaluation process during end-of-semester exams at the Institute of Education, University A.

The development of the MCDT involved meticulous planning, preparation, review, and revision. The standardized tests were validated to align with the chemistry curriculum at the Colleges of Education, ensuring they met the learning objectives [31]. Piloting the tests with pre-service teachers from non-selected colleges helped analyze their scores to confirm the tests' consistency and effectiveness in measuring the intended constructs.

Questionnaire (Adapted Newman Hierarchical Error Model)

A questionnaire was designed for data collection during the study's quantitative phase. It included both open-ended and closed-ended questions to gather participants' responses to standardized items, aiming to measure specific variables and test hypotheses [41]. The questionnaire was adapted from the Newman Hierarchical Error Model to fit the context of the Colleges of Education in Ghana.

The questionnaire was structured into three distinct sections. The first section aimed to gather basic participant details by focusing on demographic information. The second section was dedicated to questions specifically related to the mole concept, exploring the participants' understanding and insights. Finally, the third section sought suggestions from pre-service teachers on effective teaching methods for conveying the mole concept, allowing them to share their perspectives and recommendations.

Section B used a 5-point Likert scale, chosen because scales with five or more points can be used continuously without negatively impacting analysis [51]. A scale with more points generally improves reliability and validity, as fewer points can reduce correlations and reliability.

Organization of the Research Instrument

The research instrument, including the questionnaire, is organized into three main sections, as detailed above:

Table 2. Research questionnaire.

SECTION	CONTENT	NUMBER OF ITEMS
A	Demographic data of respondents	4
B	Questions related to mole concept.	14
C	Suggestions from pre-service teachers on how tutors should teach the concepts of mole	1

3.4. Interview Protocols

Semi-structured interview protocols were used to gather detailed responses and opinions from pre-service teachers. Predetermined questions were asked, aligned with the study's research questions. These interviews, lasting 20-25 minutes, offered a flexible method to explore complex topics, ensuring a deep understanding and capturing rich data. Initial greetings and assurances of confidentiality were provided. Post-interview data were manually transcribed and sent to respondents for verification.

3.5. Validity and Reliability

The study's test measured understanding of the mole concept, with reliability evaluated using the Kuder Richardson (KR-20) coefficient, achieving a value of 0.70, indicating strong internal consistency. The development of instruments was supervised by experts, piloted, and reviewed for reliability. The modified questionnaire was tested in selected Colleges of Education.

Pre-testing of Questionnaire and Test

The questionnaire and test identified challenges in understanding the mole concept among 30 pre-service teachers, consisting of 19 males and 11 females. Reliability was assessed using Cronbach's alpha coefficients, yielding values of 0.808 and 0.871, indicating high reliability. Validated items were used for all assessments.

3.6. Credibility

Credibility involves ensuring research findings match reality. Member checks/respondent validation were used to confirm the accuracy of transcriptions and emerging themes, minimizing misinterpretation and bias.

3.7. Consistency and Dependability

Qualitative research seeks to describe experiences as perceived by participants, emphasizing the consistency of results with collected data. Triangulation, peer examination, and independent research validation were employed to ensure consistency and dependability.

3.8. Transferability

Transferability refers to the applicability of study findings to other contexts. Descriptive data were provided to facilitate this, and meticulous sample selection ensured representation of all Ghanaian colleges offering chemistry. Findings were grounded in original data, confirmed through participant validation.

3.9. Data Collection Procedures

Data collection involved a systematic approach, beginning with an introductory letter from the university. Heads of departments and principals were contacted for consent, and pre-service teachers were briefed. Data from tests, questionnaires, and interviews were collected from 1200 participants across six colleges, with 11 students not participating for various reasons.

3.10. Qualitative Data Transcription

Transcription involved converting audio recordings to text, with pre-coding and coding for analysis. Backup copies of data were maintained, and member verification was conducted to ensure authenticity.

Capturing and Cleaning of the Quantitative Data

Quantitative data from 1200 pre-service teachers were entered into SPSS and double-checked for accuracy. Data cleaning involved verifying logic and checking for outliers.

3.10.1. Data Analysis Procedures

Statistical techniques such as frequencies, percentages, mean, standard deviation, factor analysis, and regression were used to analyze demographic data and answer research questions regarding student challenges in learning the mole concept.

3.10.2. Ethical Considerations

Ethical considerations included obtaining permission from the University's Ethical Committee, securing participant consent, ensuring anonymity and confidentiality, and adhering to ethical guidelines to maintain scientific integrity and trustworthiness.

4. Results and Discussion

The study aimed to identify and address the challenges pre-service teachers face in understanding the mole concept. It focused on identifying common challenges, categorizing these challenges, determining the most significant challenges, understanding their impact on learning, and finding solutions. This section presents the findings from the data collected, providing answers to each research question and making recommendations to improve the learning and performance of pre-service teachers in the mole concept.

4.1. Presentation of Results and Interpretation

Research Question One: What are the prevalent misconceptions and challenges demonstrated by pre-service teachers in the learning and instruction of the mole concept in chemistry?

This research question aimed to identify the specific challenges students face when learning the mole concept. Data was collected through items designed based on literature and analyzed using mean and standard deviation. Responses were rated on a five-point Likert scale: strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5). A mean value above 3.0 indicated general agreement with the statements, while a mean value below 3.0 indicated disagreement. A mean of 3.0 showed neutrality. The summarized responses and analysis are presented in Table 3.

Table 3. *Students' challenges in learning mole concept.*

Errors	Mean	Std. Deviation
Translating worded problems to equations	3.11	1.236
Writing appropriate balanced chemical equation	2.87	1.405
Determining the correct mole ratio	3.33	1.174
Comprehension issues with the ideas of mass, volume, mole, number of particles, and their linkages	2.81	1.336
Difficult working to come out with empirical/ molecular formulae	3.09	1.449
Difficult understanding the meaning of relationship between stoichiometric coefficient and moles in a balanced chemical equation	3.80	1.289
Difficulty in the awareness of the relationship between mole and concentration in mol/dm3	2.63	1.345
Difficulty applying the concept of concentration in mol/dm3 to solve problems involving reactions in solutions	2.82	1.324
Challenges made when manipulating integrated values, such as concentration, because of a deficiency in mathematical knowledge	2.80	1.384

Field survey, Michael Owusu (2023)

Students' Challenges in Learning the Mole Concept (Table 3).

The data in Table 3 reveal that students agreed with several statements regarding difficulties they face in learning the mole concept and redox reactions. The mean scores for these statements were above the midpoint of 3.0, indicating a consensus on the presence of these errors. Key areas of difficulty included:

1. Translating worded problems into equations (M=3.11, SD=1.236)
2. Determining the correct mole ratio (M=3.33, SD=1.174)
3. Working to determine empirical/molecular formulae (M=3.09, SD=1.449)

4. Understanding the relationship between stoichiometric coefficients and moles in balanced equations (M=3.80, SD=1.289)
5. Solving problems without using formulae (M=3.17, SD=1.412)
6. Reading problems involving oxygen, hydrogen, electrons, and oxidation numbers (M=3.33, SD=1.324)
7. Recognizing that reduction and oxidation reactions occur simultaneously (M=3.27, SD=1.241)
8. Understanding questions regarding hydrogen, oxygen, electrons, and oxidation numbers (M=3.20, SD=1.288)
9. Believing oxygen always plays a role in redox reactions (M=3.31, SD=1.363)
10. Considering oxygen in molecules as the oxidizing agent (M=3.21, SD=1.318)
11. Identifying what to use for solving redox questions (M=3.76, SD=1.193)
12. Writing half-reaction steps (M=3.52, SD=1.320)

Conversely, students disagreed with statements concerning their ability to write balanced chemical equations, understand concepts like mass, volume, and concentration, and recognize oxidation and reducing agents. These statements had mean scores below the midpoint of 3.0, highlighting lesser agreement on these issues.

From these findings, it is inferred that pre-service teachers face significant challenges in specific areas of learning the mole concept. These include translating problems, determining mole ratios, and understanding stoichiometric relationships, among others. Interviews with selected pre-service teachers from six colleges, coded as S1, S2, etc., provided additional insights into these errors. The responses were analyzed using narrative analysis based on identified themes.

S1 *Concerning some of the challenges I commit in learning mole concept, sometimes the very error I commit is I fail to convert worded problems to equations.*

S2 *I have a big challenge when it comes to working questions in mole concept. I have difficulties in solving problems without the use of formulae. For example, I can't calculate the number of moles in a given compound without the use of formular, but if I am using formular, oh it's easy.*

S3 *I don't have so much difficulties in the mole concept, except that of identifying the mole ratio in an equation. I have difficulty in determining the correct mole ratio, because I see the ratios as different from the coefficients of the various compounds.*

S4 *During secondary school days, my chemistry teacher used to tell us that it's a waste of time solving mole concept questions using principles. All you need is your formular, therefore, we were made to memorize almost all the formulae regarding the calculations especially after doing titration experiments. Because of that I have difficulties in solving problems in mole concept without the use of formulae.*

S5 *For mole concept, I don't have any problem is just when it comes to the di-atoms, finding the number of atoms in the di-atom that's where I sometimes get confused whether we are to multiply the number given by the two or we are to use it in working but apart from that I don't have any problem with mole concept.*

S6 *For the mole concept I was a little bit uncomfortable, but it seems it was SHS that I did it and since then, I did not attend to my books so remembering the formulae was difficult. Meanwhile, apart from the formulae, my chemistry tutor back in SHS didn't teach us the principles. I also have problems with concentration and relative molecular formula.*

S7 *The area in which I found some difficulties in mole concept is reading the problem and trying to get what the question is asking for and finding solutions to it. I don't really understand the questions and how to get answers to it. From my perspective what I think is the problem is when I was in SHS our chemistry teacher went on transfer and so we had no chemistry teacher until when we were in SHS 3 and so we didn't learn most of the topics in chemistry and that didn't help me at all. It has made me not understand most of the topics in chemistry.*

S8 *Some of the challenges I have in mole concept are the calculations, the use of the concept and applications and what to be used in solving the questions and difficulties in reading the problem. I don't really understand it at all when I read the question.*

S9 *Sometimes it is very difficult in solving mole concepts because I forget the unit. Without the units, everything is wrong.*

S10 *The biggest error I usually commit when solving questions involving mole concept is changing the questions into equations. That one isn't easy at all. It's not my making because I wasn't taught at SHS because at my school we didn't get chemistry masters.*

S11 *Back in the SHS, our chemistry tutor prepared chemistry questions and an answer booklet for us. Anytime we do practical on mole concept in chemistry, we used the pamphlet in solving it since all the solutions were in it. These solutions were mainly formular work. Because of this I'm used to solving mole concepts using formular and without it, I'll find it more difficult in solving.*

S12 *On the concept of mole, I've difficulty understanding the relationship between stoichiometric coefficient and mole ratio in chemical equations. As a result, I don't like questions of that nature, apart from that, I'm ok with mole concepts.*

Based on the results, it can be inferred that pre-service teachers face several challenges in learning redox reactions and the mole concept. These challenges include:

1. Translating worded problems into equations
2. Determining the correct mole ratio
3. Working to determine empirical/molecular formulae
4. Grasping the link between stoichiometric coefficients and moles in balanced equations
5. Solving problems without formulae

Selected pre-service teachers from six colleges were interviewed about these challenges. Their responses were analyzed using narrative analysis based on identified themes. Students were coded as S1, S2, and so on, with their responses presented in excerpts.

S1 *Concerning some of the challenges I commit in learning mole concept, sometimes the very error I commit is I fail to convert worded problems to equations.*

S2 *I have a big challenge when it comes to working questions in mole concept. I have difficulties in solving problems without the use of formulae. For example, I can't calculate the number of moles in a given compound without the use of formular, but if I am using formular, oh it's easy.*

S3 *I don't have so much difficulties in the mole concept, except that of identifying the mole ratio in an equation. I have difficulty in determining the correct mole ratio, because I see the ratios as different from the coefficients of the various compounds.*

S4 *During secondary school days, my chemistry teacher used to tell us that it's a waste of time solving mole concept questions using principles. All you need is your formular, therefore, we were made to memorize almost all the formulae regarding the calculations especially after doing titration experiments. Because of that I have difficulties in solving problems in mole concept without the use of formulae.*

S5 *For mole concept, I don't have any problem is just when it comes to the di-atoms, finding the number of atoms in the di-atom that's where I sometimes get confused whether we are to multiply the number given by the two or we are to use it in working but apart from that I don't have any problem with mole concept*.

S6 *For the mole concept I was a little bit uncomfortable, but it seems it was SHS that I did it and since then, I did not attend to my books so remembering the formulae was difficult. Meanwhile, apart from the formulae, my chemistry tutor back in SHS didn't teach us the principles. I also have problems with concentration and relative molecular formula.*

S7 *The area in which I found some difficulties in mole concept is reading the problem and trying to get what the question is actually asking for and finding solutions to it. I don't really understand the questions and how to get answers to it. From my perspective what I think is the problem is when I was in SHS our chemistry teacher went on transfer and so we had no chemistry teacher until when we were in SHS 3 and so we didn't learn most of the topics in chemistry and that didn't help me at all. It has made me not understand most of the topics in chemistry.*

S8 *Some of the challenges I have in mole concept are the calculations, the use of the concept and applications and what to be used in solving the questions and also difficulties in reading the problem. I don't really understand it at all when I read the question.*

S9 *Sometimes it is very difficult in solving mole concepts because I forget the unit. Without the units, everything is wrong.*

S10 *The biggest error I usually commit when solving questions involving mole concept is changing the questions into equations. That one isn't easy at all. It's not my making because I wasn't taught at SHS because at my school we didn't get chemistry masters.*

S11 *Back in the SHS, our chemistry tutor prepared chemistry questions and an answer booklet for us. Anytime we do practical on mole concept in chemistry, we used the pamphlet in solving it since all the solutions were in it. These solutions were mainly formular work. Because of this I'm used to solving mole concept using formular and without it, I'll find it more difficult in solving.*

S12 *On the concept of mole, I've difficulty understanding the relationship between stoichiometric coefficient and mole ratio in chemical equations. As a result, I don't like questions of that nature, apart from that, I'm ok with mole concept.*

The responses revealed that most students struggle to solve mole concept problems without using formulae. Additionally, many pre-service teachers indicated challenges in translating worded problems into chemical equations and understanding the questions. These interview results confirm the findings from the quantitative data.

5. Discussion

5.1. Research Question One

What are the students' challenges in learning the mole concept?

This research aimed to identify students' challenges in learning the mole concept. The study revealed that students' challenges included:

1. Translating worded problems to equations
2. Determining the correct mole ratio
3. Working out empirical/molecular formulae
4. Understanding the link between the stoichiometric coefficient and moles in a balanced chemical equation
5. Solving problems without the use of formulae

The study confirmed that these difficulties stem from a failure to conceptualize the mole concept [23]. Students lacked a deep understanding of what the mole concept means, which was attributed to factors such as the SI definition of the mole, the nature of the surrounding knowledge, and the teaching methods used by teachers and textbooks [4, 57].

According to studies, the mole concept is one of the most challenging topics in teaching and learning, often frustrating students [33]. It is noted that students' unfamiliarity with the mole concept leads them to memorize equations and answers rather than understanding them [9]. This lack of comprehension is problematic for scientific experiments requiring precise understanding of the mole concept, as noted by [7, 39].

Research has found that many teachers also struggle with the mole concept, which hinders students' understanding. Misdefinitions in teaching materials like textbooks further complicate learning [9, 49]. Students who struggle with the mole concept also find it difficult to learn related topics, particularly stoichiometry, where the mole concept is central [25].

It is demonstrated that students struggle with stoichiometric calculations due to the need to grasp various aspects such as the mole concept, balancing chemical equations, performing algebraic operations, and translating word problems into mathematical equations [18]. They also need a solid understanding of mole ratio and proportion.

The research suggests that chemistry teachers may not be using effective teaching approaches, as difficulties with the mole concept are common among secondary school students. Therefore, teaching challenging concepts like the mole concept requires a learner-centered and innovative approach to engage students effectively.

Research Question Two:

What ways do constructivist teaching approaches affect pre-service teachers' comprehension and pedagogical effectiveness related to the mole concept?

This section explores remedies suggested by pre-service teachers for improving the teaching of the mole concept per the constructivists teaching approach. Key recommendations include:

1. Thorough Teaching: Teachers should allocate sufficient time to teach the mole concept comprehensively, addressing assumptions that pre-service teachers have prior knowledge from SHS and managing time constraints effectively.
2. Effective Teaching Strategies: Employing hands-on and activity-based teaching strategies in laboratories can enhance understanding. Constructivist approaches, which involve active participation and collaboration among students, are recommended [1, 14, 58].
3. Use of Teaching and Learning Resources: Teachers should utilize available resources and ensure they are employed effectively in teaching. Preparation and understanding of the mole concept by teachers are crucial for effective instruction [12, 15].
4. Collaborative Learning: Encouraging small group work and participatory learning to facilitate problem-solving and peer evaluation can enhance understanding [32, 48].
5. Mastery of Pedagogical Content Knowledge (PCK): Teachers should develop strong PCK to connect subject matter with effective teaching strategies, addressing students' specific learning difficulties [13, 26, 45]. Overall, the study emphasizes the need for teachers to ensure a thorough understanding of the mole concept, employ effective teaching strategies, and use participatory and collaborative learning methods to help students grasp complex chemical concepts.

5.2. Integration of Cognitive and Instructional Challenges

The cognitive challenges faced by students, such as difficulty in understanding the mole concept and applying it in problem-solving, are closely intertwined with the instructional challenges identified in the study. The failure to effectively teach the mole concept in a way that promotes deep conceptual understanding rather than rote memorization has a direct impact on students' cognitive development. Constructivist teaching approaches, which focus on active engagement and collaboration, offer a potential solution to both sets of challenges. By shifting the focus from traditional lecture-based methods to more interactive and student-centered learning experiences, teachers can help students overcome their cognitive barriers and develop a more robust understanding of the mole concept.

Furthermore, the qualitative findings suggest that students' reliance on formulae without understanding the underlying concepts reflects a broader issue in science education: the need to foster critical thinking and problem-solving skills. Teachers must address this by using instructional strategies that promote inquiry-based learning, encouraging students to ask questions, explore different approaches, and reflect on their learning process [2]. This approach not only improves students' comprehension of the mole concept but also enhances their overall ability to tackle complex problems in chemistry.

In conclusion, addressing the cognitive and instructional challenges related to the mole concept requires a multifaceted approach. Teachers need to adopt constructivist strategies that engage students in active learning, provide ample opportunities for collaborative problem-solving, and ensure a thorough understanding of the concept. Additionally, teachers must continuously improve their pedagogical content knowledge to effectively address students' misconceptions and learning difficulties, thereby enhancing their comprehension and pedagogical effectiveness in teaching the mole concept.

6. Conclusion

The study aimed to address pre-service teachers' challenges in understanding the mole concept using a mixed-method explanatory research design. The research involved chemistry students from six colleges of education in various regions of Ghana. Through purposive sampling, 1211 pre-service teachers were selected. They took tests on mole concepts, completed questionnaires, and participated in interviews.

6.1. Key Findings

1. Challenges in Learning Mole Concept:
    1) Difficulty translating word problems into equations.
    2) Incorrect determination of mole ratios.
    3) Issues with deriving empirical/molecular formulae.
    4) Misunderstanding the relationship between stoichiometric coefficients and moles.
    5) Inability to solve problems without formulae.
2. Categorization of challenges:
    1) Comprehension challenge (understanding the question).

2) Transformation challenge (identifying the solving method).
3) Process skills challenge (working steps to find the answer).
4) Encoding challenge (final answer presentation).

3. Main Contributing challenges:
1) Process skills challenge (β =.415)
2) Transformation challenge (β =.347)
3) Comprehension challenge (β =.228)
4) Encoding challenge (β =.224)

4. Influence of Challenges on Learning:
1) Weak positive, not significant influence from quantitative data ($r = .007$, $p < 0.05$).
2) Qualitative data showed students struggled without formulae and disliked calculation-based questions.

5. Remedies for Learning challenges:
1) Tutors should ensure proper, thorough teaching.
2) Implement small group collaborative learning.
3) Avoid rote memorization, emphasize understanding.
4) Tutors need better content knowledge of the mole concept.
5) Implications to teaching, learning and assessment

The implications of the study for teaching are significant, as it underscores the need for educators to adopt more effective instructional strategies that focus on conceptual understanding rather than rote memorization of the mole concept. Teachers should employ active learning techniques, such as problem-based learning and collaborative exercises, to help students grasp complex ideas. Furthermore, educators need to deepen their pedagogical content knowledge and utilize analogies and simulations to make abstract concepts more relatable and comprehensible. This approach will enable them to better address and correct student misconceptions and errors.

For learning and assessment, the study highlights the importance of focusing on students' conceptual understanding of the mole concept. Active learning environments that encourage engagement through discussions and hands-on activities can significantly enhance comprehension. Additionally, assessments should evaluate students' understanding beyond formula application, using diagnostic tools like the Mole Concept Diagnostic Test (MCDT) to identify and address specific learning challenges. Detailed feedback and reflection on assessments will help students recognize and correct their misunderstandings, leading to improved educational outcomes and a stronger grasp of fundamental chemical principles.

6.2. Conclusions

Many pre-service teachers struggle with converting word problems into equations.

Students often don't understand the questions or how to systematically solve them.

Most cannot solve problems without formulae, indicating a lack of conceptual understanding.

Interviews revealed tutors often lack pedagogical content knowledge.

Tutors assume the mole concept is covered in SHS and do not emphasize it enough in teaching.

Small group and cooperative learning methods are recommended.

Contributions of the Study

1. Empirical Gaps in Literature:
i. Addressed challenges made by pre-service teachers rather than SHS students.
ii. Provided a novel categorization of errors.

2. Research Methodology:
i. Utilized a sequential explanatory design mixed method.
ii. Combined quantitative test data and qualitative interview data.

3. Professional Development of Teachers:
i. Participating pre-service teachers gained insights and professional development.
ii. Research protocols could be used for training field teachers.

6.3. Recommendations

1. Tutors should design tests to assess conceptual understanding and teach the language of mole concepts.
2. Teach students to write and balance chemical equations to determine correct mole ratios.
3. Help students understand the meaning of mole and derive formulae from percentage composition.
4. Use analogies and simulations for teaching stoichiometry.
5. Emphasize understanding principles over memorizing formulae.

6.4. Suggestions for Further Studies

The study was limited to six colleges under University A. Future research should include other colleges and universities and explore other chemistry concepts.

Abbreviations

CK	Content Knowledge
PCK	Pedagogical Content
MCDT	Mole Concept Diagnostic Test
IUPAC	International Union of Pure and Applied Chemistry

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

Questionnaires For Students on Mole Concept

Dear respondent,

The purpose of this study is to identify and find solutions to pre-service teachers' challenges in learning mole concept. You are kindly requested to provide your candid opinions on the items in this instrument. Your responses to these items will be treated with utmost confidentiality. Thank you for your cooperation.

INSTRUCTION: Tick (√) the column that is applicable to your opinion.

Appendix I: Background Data of Respondents

School: ……………………………………………………………………………………

Gender of respondent: Male [ ] Female [ ]

Programme of study: Primary Education [ ] JHS Education [ ]

Early Grade Education [ ]

Appendix II: Instruction: Tick (√) the Column That Is Applicable to Your Opinion on the Likert Scale of Items of Section B

Table 4. Pre-SERVICE TEACHERS' CHALLENGES WHEN LEARNING MOLE CONCEPT.

Key: 'SD' – 1 (Strongly Disagree), 'D' – 2 (Disagree), 'N' – 3 (Neutral), 'A' – 4 (Agree) 'SA' – 5 (Strongly Agree).

Item	Challengespre-service teachers commit when learning mole concept	SD	D	N	A	SA
	During learning of mole concept, I find it more difficult:					
1	Translating worded problems to equations					
2	Writing appropriate balanced chemical equation					
3	Determining the correct mole ratio					
4	Solving problems without the use of formulae					
	Challenge categories pre-service teachers commit					
	The error(s) I commit during learning of mole concept is/are shown below:					
5	What the question is asking for (Comprehension)					
6	What to be used in solving the question (Transformation)					
7	Cannot show working steps I will use to arrive at answer (Process skills)					
8	I find it difficult getting answer final answer (Encoding)					
	Challenges that contribute most to my difficulties in solving mole problems					
9	What the question is asking for (Comprehension)					
10	What to be used in solving the question (Transformation)					
11	Cannot show working steps I will use to arrive at answer (Process skills)					
12	I find it difficult getting answer final answer (Encoding)					
	How do the challenges influence my learning of mole concept					
13	I just do not like the concept of mole					
14	Mole is interesting and easy to understand					
15	I am not motivated in learning mole concept because my chemistry teachers at the secondary school never encourage me during mole concept lessons					

Appendix III: Remedies on How Tutors Are to Teach the Mole Concept and Redox Reactions to Pre-service Teacher at Colleges of Education

33. In your views, how should the mole concept be taught by tutors to pre-service teachers at the Colleges of Education?...

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