Fragmented Conceptual Understanding and Quantitative Challenges in Stoichiometry and Chemical Reactions among Grade 12 Students

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ABSTRACT

This study investigated the conceptual understanding of stoichiometry and chemical reactions among Grade 12 senior high school learners and developed a standardized diagnostic questionnaire to identify least mastered competencies. Employing a descriptive research design with an instrument development and survey approach, the study involved seventy four (74) Grade 12 learners from a public senior high school for the main assessment, while pilot testing was conducted with one hundred fifty (150) learners from two other schools to establish the instrument's reliability and validity. Data were analyzed using descriptive statistics and item analysis to determine mastery levels across selected chemistry competencies aligned with the K–12 Most Essential Learning Competencies (MELCs). Results indicated generally low mastery, with a Mean Percentage Score (MPS) of 54.86, classified as not mastered. Learners exhibited the greatest difficulty with quantitatively oriented competencies, including determining molar mass and calculating mass, moles, and number of particles. Other least mastered competencies included identifying types of chemical reactions, writing balanced chemical equations using the Law of Conservation of Mass, and explaining the mole concept. Conversely, learners demonstrated relatively better performance in recognizing chemical reactions in environmental and biological contexts, suggesting stronger familiarity with observable phenomena than with abstract or mathematical concepts. The findings reveal fragmented conceptual understanding and limited integration of quantitative reasoning in senior high school chemistry learning. The validated diagnostic questionnaire provides a practical tool for identifying learners' conceptual gaps and informing targeted instructional interventions. These results underscore the need for teaching strategies that enhance conceptual clarity, quantitative problem-solving, and real-world application of stoichiometry and chemical reactions.

Keywords: chemical reactions, conceptual understanding, stoichiometry, chemistry education

INTRODUCTION

Chemistry constitutes a core component of the Science, Technology, Engineering, and Mathematics (STEM) strand in senior high school programs in the Philippines (Republic Act No. 10533, 2013). Despite its curricular significance, learners frequently encounter difficulties with fundamental concepts, particularly in stoichiometry, which integrates abstract chemical reasoning with quantitative problem-solving (BouJaoude et al., 2000; Nucum, 2017). Stoichiometry involves the systematic analysis of reactant and product quantities in chemical reactions, necessitating mastery of the mole concept, molar mass, chemical formulas, and balanced chemical equations (Zumdahl, 2003).

Persistent misconceptions in stoichiometry, including misunderstandings of limiting reagents, theoretical yield, and excess reactants, impede students' problem-solving efficacy and overall performance in chemistry (Chandrasegaran et al., 2009; Sostarecz & Sostarecz, 2012). Furthermore, research indicates that learners often develop algorithmic proficiency without accompanying conceptual understanding, resulting in fragmented and superficial knowledge structures (Nyachwaya et al., 2014; Sanger, 2005). Within the Philippine context, the lack of standardized diagnostic instruments to systematically assess mastery levels in stoichiometry constrains educators' capacity to implement evidence-based interventions.

In alignment with United Nations Sustainable Development Goal 4, which emphasizes inclusive and equitable quality education (United Nations, 2015), this study seeks to: (1) identify the least mastered competencies in stoichiometry among senior high school learners, (2) evaluate overall mastery levels, and (3) develop a validated,

standardized diagnostic questionnaire. By generating an empirically grounded assessment tool, the study aims to inform instructional strategies, enhance conceptual understanding, and address persistent gaps in quantitative chemical reasoning.

METHODOLOGY

Research Design. A descriptive research design incorporating instrument development and survey methodologies was employed. This approach facilitated the systematic description of learners' conceptual understanding, the identification of least mastered competencies, and the creation of a validated diagnostic instrument without experimental manipulation of instructional variables.

Research Setting and Participants. The study was conducted at Libertad National High School, Misamis Oriental, Philippines, involving 74 Grade 12 learners from the STEM and HUMSS strands. Pilot testing of the diagnostic instrument engaged 150 learners from Manticao National High School and Cabalantian National High School (75 learners from each) to establish reliability and content validity. Participants were fully informed of the study's objectives, and their involvement was voluntary. Ethical considerations, including informed consent and confidentiality, were observed throughout the research process.

Research Instrument. The primary research instrument was a researcher-developed standardized diagnostic questionnaire, grounded in the K–12 Most Essential Learning Competencies (MELCs) and corroborated by extant literature on stoichiometry instruction and learning difficulties. The initial version comprised 50 multiple-choice items, which were subsequently refined to 40 items for the main assessment. The questionnaire addressed key stoichiometry topics, including: The mole concept and molar mass, Balancing chemical equations, Mole ratios, Limiting reactants, Theoretical and percent yield, Types of chemical reactions, Predicting reaction products.

Each correct response was awarded one point, and total scores were used to determine mastery levels. To ensure validity and reliability, the instrument underwent expert evaluation by senior chemistry educators and researchers, assessing clarity, alignment with curriculum standards, and content relevance. Pilot testing facilitated item analysis, including calculations of difficulty indices, discrimination indices, and internal consistency reliability, thereby ensuring that the instrument effectively distinguished between high- and low-performing learners.

Table 1 and 2 summarizes the descriptors of learners' conceptual understanding and the mastery levels of learners across the key topics in Chemistry 10, accompanied by their corresponding percentage scores, offering a comprehensive quantitative overview of student performance across the curriculum.

Table 1. Interpretation of Learners' Conceptual Understanding

Percentage	Descriptors	Interpretation
90- 100	Outstanding	Very High
85-89	Very Satisfactory	High
80-84	Satisfactory	Average
75-79	Fairly Satisfactory	Low
Below 75	Did Not Meet Expectation	Very Low

Reference: DepEd Order No. 8, s. 2015

Table 2. Mastery Levels and Percentage Equivalent

Mastery Level	**Percentage Equivalent**
Mastered	80-100
Nearly Mastered	75-79
Least Mastered	51-74
Not Mastered	50 and below

Reference: DepEd PPST -Module 11

Data Collection Procedure. Data collection for this study was conducted through a systematic, multi-phase process to ensure the validity and reliability of the standardized diagnostic questionnaire. Initially, a 50-item multiple-choice draft was developed based on the K–12 Most Essential Learning Competencies (MELCs) and an extensive review of relevant literature, encompassing key topics in stoichiometry and chemical reactions. The draft instrument was subsequently subjected to expert evaluation by senior chemistry educators to assess content relevance, clarity, curricular alignment, and appropriateness of difficulty. Revisions were implemented based on their feedback.

Following instrument refinement, ethical clearance and administrative permission were obtained from the participating schools, ensuring voluntary participation and the confidentiality of student responses. The questionnaire was then pilot-tested with 150 Grade 12 learners from Manticao National High School and Cabalantian National High School—distinct from the main study sample—to evaluate item clarity, reliability, and suitability. Based on pilot testing outcomes and expert recommendations, the instrument was revised and reduced to 40 items, forming the final standardized diagnostic tool.

The finalized questionnaire was administered to 74 Grade 12 learners at Libertad National High School, representing both STEM and HUMSS strands. Each correct response was scored as one point. The collected data were subsequently analyzed using descriptive statistics and item analysis to determine learners' mastery levels, identify least mastered topics, and provide empirical evidence to inform targeted instructional interventions.

Data Analysis. Descriptive statistical techniques—including mean scores, percentages, and frequency counts—were employed to evaluate learners' conceptual understanding and classify mastery levels. Item analysis was conducted to determine topic-specific difficulties, with overall mastery categorized as high, moderate, or low, thereby facilitating identification of areas requiring focused pedagogical support.

Ethical Considerations. The study adhered to ethical standards in educational research. Participants' confidentiality and voluntary participation were strictly maintained. No physical or psychological harm occurred, and all data were handled securely. The research design avoided deception, and results were reported honestly and accurately in accordance with ethical research practices.

RESULTS AND DISCUSSION

Learners' Conceptual Understanding. Analysis of the standardized diagnostic questionnaire revealed a generally low level of conceptual understanding, with an overall Mean Percentage Score (MPS) of 54.86, classified as Not Mastered. Out of the 74 learners assessed, only 13 achieved passing scores, while the majority performed below the expected mastery threshold.

Quantitative competencies were particularly challenging for learners. Determining molar mass yielded only 46.4% correct responses, while calculating mass, moles, and number of particles achieved 39.41% correct. These results are consistent with prior research documenting learners' difficulties in integrating mathematical reasoning with chemical concepts (Wu & Krajcik, 2006; Bayarcal & Tan, 2023; Barker & Kind, 2004; Davidowitz et al., 2010), highlighting persistent conceptual and procedural gaps in stoichiometry.

Least Mastered Competencies. Analysis of the diagnostic assessment revealed that several competencies were consistently identified as least mastered among Grade 12 learners. These included Identifying and classifying types of chemical reactions, such as combination, decomposition, single- and double-displacement, combustion, and acid–base reactions; Writing balanced chemical equations in accordance with the Law of Conservation of Mass; Explaining the mole concept and its applications in quantitative chemical reasoning; and Describing the environmental implications of chemical reactions.

These findings underscore persistent conceptual gaps in stoichiometry and reaction-related competencies, reflecting learners' difficulties in integrating symbolic representations, quantitative calculations, and real-world applications. Such patterns are consistent with prior research both globally and within the Philippine context, which demonstrates that students frequently exhibit fragmented understanding and entrenched misconceptions in chemical representations and stoichiometric reasoning (Chandrasegaran et al., 2009; Astuti et al., 2025; Ogundiji, 2024).

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Table 3 further presents the performance of the learners, including percentage scores and their corresponding interpretations. The data indicate that most respondents achieved less than 75%, which, according to the established grading criteria, classifies their performance as failing. These results collectively highlight substantial gaps in learners' understanding of stoichiometry and chemical reactions.

Table 3. Least Mastered Stoichiometry and Reactions Competencies

Learning Competencies	**Frequency of Error**	**%**	**No of Correct Responses**	**%**	**Mastery Level**
Use secondary sources to identify examples of synthesis/ combination, decomposition, single displacement, double displacement, combustion and acid-base reactions	451	46.88	511	53.12	Least Mastered
Write the balanced chemical equations of various chemical reactions in real-life scenarios by applying the Law of Conservation of Mass	235	45.37	283	54.63	Least Mastered
Identify examples of chemical reactions that occur in the environment and in living things, such as photosynthesis, respiration, digestion, hydrolysis, oxidation-reduction	19	25.68	55	74.32	Least Mastered
Explain the development and importance of the Mole Concept	243	46.91	275	53.09	Least Mastered
Determine the molar mass of a number of common elements, such as hydrogen, oxygen, magnesium, lead, sodium and chlorine, and the molar mass of a number of common compounds, such as water, sodium chloride and carbon dioxide	119	53.6	103	46.4	Not Mastered
Calculate mass, mole, and number of particles in a given chemical reaction such as in respiration, photosynthesis, and environmental and industrial reactions;	269	60.59	175	39.41	Not Mastered
Describe the environmental effects of various chemical reactions by examining their efficiency and byproducts, and suggest ways to minimize their negative impacts	82	36.94	140	63.06	Least Mastered
Mean Percentage Score	**54.86**				**Not Mastered**

Respondents' Score Distribution. Figure 1 illustrates the distribution of scores obtained by the respondents on the researcher-developed diagnostic questionnaire assessing stoichiometry and chemical reactions.

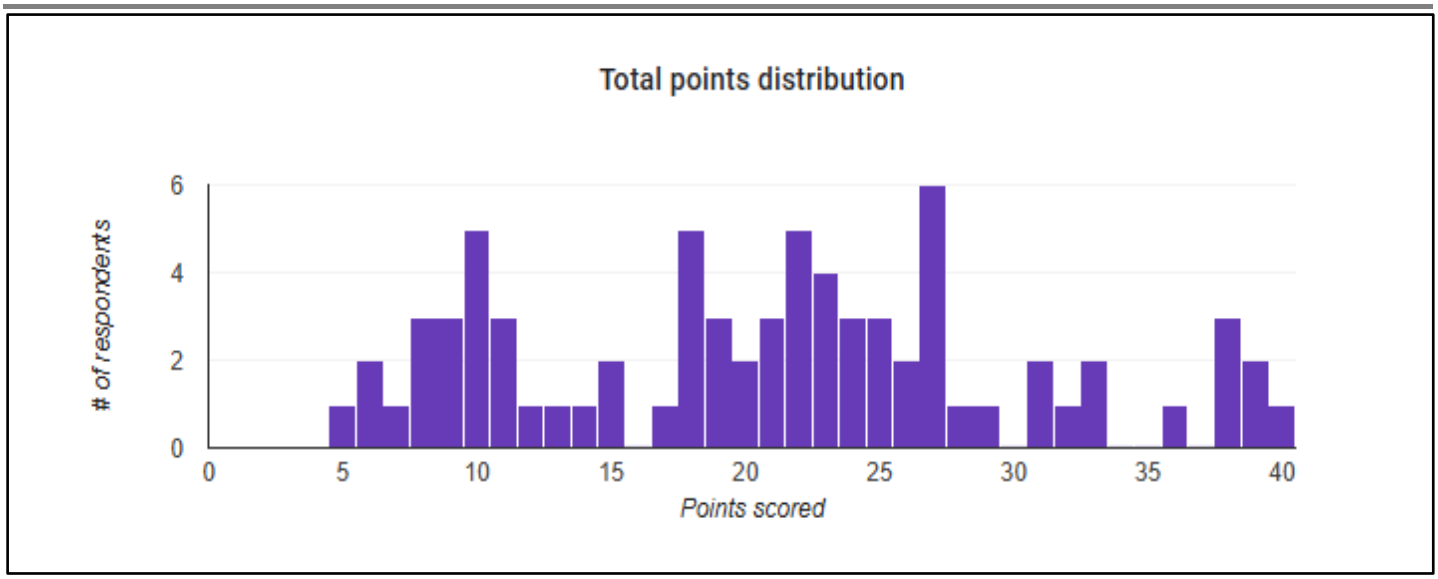

Figure 1. Total Points Distribution

Scores ranged from 5 to 40 points, with a majority of learners scoring 27 and an overall mean of 21. The figure reveals a left-skewed distribution, indicating that most respondents clustered in the lower score range, reflecting limited mastery of the assessed competencies.

CONCLUSION AND RECOMMENDATION

The findings of this study indicate that Grade 12 learners exhibit generally low mastery of stoichiometry and chemical reactions, particularly in competencies requiring quantitative reasoning and abstract conceptualization. Skills such as determining molar mass, calculating moles and mass, writing balanced chemical equations, and explaining the mole concept were identified as the least mastered. In contrast, learners performed relatively better in identifying types of chemical reactions in observable or practical contexts, suggesting familiarity with phenomenological aspects but limited capacity for abstract chemical reasoning.

These results underscore the need for targeted instructional strategies that integrate conceptual understanding with quantitative problem-solving, scaffold learners' cognitive processes, and contextualize abstract chemical concepts within real-world scenarios. The standardized diagnostic questionnaire developed in this study provides a valid and reliable instrument for identifying learners' conceptual gaps, guiding evidence-based instructional decisions, and fostering meaningful engagement with chemistry.

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