Foundational Chemistry Learning Gaps in Atomic Structure and the Periodic Table: Development and Application of a Diagnostic Mastery Assessment

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ABSTRACT

This study aimed to develop a valid and reliable assessment instrument and to determine the mastery levels of Grade 11 learners in Atomic Structure and the Periodic Table of Elements, which are foundational domains in senior high school chemistry. Utilizing a descriptive research design, the study involved 120 Grade 11 students from Betinan National High School as the primary respondents, while 150 senior high school students from Fatima National High School participated in the pilot testing of the researcher-developed instrument. The finalized 35-item multiple-choice mastery test underwent rigorous expert validation, item analysis, and reliability testing, yielding a high internal consistency coefficient (Cronbach's $\alpha = 0.829$). Learners' performance data were analyzed using descriptive statistical techniques, including frequency counts and percentage distributions, and mastery levels were classified as Not Mastered, Least Mastered, Nearly Mastered, or Mastered. The results revealed that learners demonstrated an overall Least Mastered level of understanding, with a mean mastery score of 47%. Both Atomic Structure (49%) and the Periodic Table of Elements (45%) were classified within the same mastery category, with the majority of assessment items exhibiting high error rates. These findings indicate persistent conceptual difficulties in key areas such as subatomic particles, atomic number and mass number, electron configuration, and periodic trends. Collectively, the results highlight substantial gaps in learners' conceptual understanding and underscore the necessity for instructional strategies that emphasize diagnostic assessment, multiple representations, and conceptually driven instruction to address misconceptions and strengthen foundational chemistry knowledge.

Key Words: Atomic Structure, Chemistry Education, Conceptual Understanding, Grade 11 Learners, Mastery Levels

INTRODUCTION

Science education plays a pivotal role in equipping learners with the conceptual tools necessary to interpret natural phenomena and to participate productively in an increasingly science- and technology-driven society. Within the science curriculum, chemistry occupies a central position because it explains the structure, properties, and transformations of matter that underpin disciplines such as materials science, medicine, engineering, and environmental studies. As a core subject in secondary education, chemistry contributes significantly to the development of scientific literacy, analytical reasoning, and problem-solving skills essential for higher education and participation in STEM-related professions (Taber, 2021; Tsaparlis & Sevian, 2022).

Despite its curricular significance, chemistry is consistently identified as a challenging subject for many learners, particularly when instruction requires abstract, symbolic, and representational reasoning. Research in chemistry education has repeatedly shown that students experience difficulty integrating macroscopic observations, submicroscopic particle-level explanations, and symbolic representations—a triadic coordination that is fundamental to meaningful chemical understanding (Johnstone, 2006; Treagust et al., 2022). These challenges are especially pronounced in foundational topics such as Atomic Structure and the Periodic Table of Elements, where learners must conceptualize entities and processes that are inherently unobservable.

Empirical studies indicate that learners frequently develop fragmented, incomplete, or alternative conceptions related to atomic models, subatomic particles, electron configuration, and periodic trends. Rather than constructing coherent explanatory frameworks, students often rely on rote memorization of isolated facts or procedural rules, resulting in superficial understanding and limited conceptual transfer. Such learning approaches constrain learners' ability to apply chemical principles to unfamiliar contexts or higher-order problem-solving situations (Taber, 2021; Chang & Park, 2023). As emphasized by Scerri (2020), meaningful understanding of the periodic table requires explanatory reasoning grounded in electronic structure and effective nuclear charge—conceptual domains that remain problematic for many learners.

Similar learning difficulties have been documented among secondary and senior high school students. While learners may demonstrate success on recall-based assessments, they frequently encounter difficulties when required to explain underlying mechanisms, interpret periodic trends, or apply atomic concepts in novel situations. This discrepancy suggests that achievement scores alone may not accurately capture learners' depth of conceptual understanding (Tsaparlis & Sevian, 2022). Recent empirical evidence reinforces this concern. Sayre et al. (2025) reported persistent deficiencies in general chemistry mastery among senior high school learners, with performance levels often falling below expected proficiency benchmarks. Likewise, Damayanti and Wulanningtyas (2025) identified widespread misconceptions related to atomic structure, element classification, and periodicity, which hinder the integration of core chemical ideas.

Research focusing specifically on atomic structure and the periodic table further highlights both conceptual and engagement-related challenges. Febriyani et al. (2025) observed that although students may exhibit high levels of behavioral engagement, deeper cognitive and emotional engagement—critical for conceptual mastery—often remains limited. Complementary qualitative and quantitative investigations continue to reveal low levels of conceptual understanding and persistent misconceptions, underscoring the enduring instructional challenges posed by the abstract and submicroscopic nature of atomic theory and periodic trends (Herdien, 2024; Damayanti & Wulanningtyas, 2025). These findings suggest that conventional instructional approaches may be insufficient for addressing learners' underlying conceptual difficulties.

Given the foundational role of Atomic Structure and the Periodic Table of Elements as prerequisites for subsequent topics such as chemical bonding, reactivity, and materials science, there is a compelling need to examine learners' mastery of these concepts systematically. Assessing mastery levels enables the identification of specific conceptual gaps, patterns of misunderstanding, and areas requiring pedagogical intervention. Accordingly, the present study aims to determine the mastery levels of Grade 11 learners in atomic structure and periodic table concepts, including subatomic particles, atomic models, electron configuration, periodic trends, and element classification. By examining both mastery levels and prevalent misconception patterns, this study seeks to generate empirical evidence to inform instructional improvement and enhance learning outcomes in secondary chemistry education.

METHODOLOGY

Research Design

This study employed a descriptive research design to systematically examine Grade 11 learners' mastery levels in Atomic Structure and the Periodic Table of Elements. The descriptive approach was deemed appropriate as it facilitates the objective measurement, organization, and interpretation of learners' conceptual understanding without manipulating instructional variables. Such a design is particularly suitable for identifying existing levels of mastery and describing patterns of learning outcomes within a defined educational context.

Participants

Purposive sampling was utilized to select participants who were most appropriate for the objectives of the study. The pilot testing phase involved one hundred fifty (150) senior high school students from Fatima National High School. This phase aimed to examine the clarity, reliability, and preliminary psychometric properties of the assessment instrument. Pilot testing was conducted across multiple class sections to minimize familiarity bias and ensure the validity of responses.

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Following item analysis and instrument refinement, the finalized assessment tool was administered to a separate cohort of one hundred twenty (120) Grade 11 students from Betinan National High School. These learners served as the primary respondents for the main data collection phase of the study.

Data Gathering Procedure

The data-gathering process was implemented in several systematic stages to ensure the validity and reliability of the research instrument. Prior to data collection, formal approval was secured from school administrators, and coordination was conducted with Grade 11 chemistry teachers to schedule the assessment administration.

The first stage involved pilot testing the researcher-developed mastery test on atomic structure and the periodic table of elements among 150 senior high school students from Fatima National High School. The pilot phase aimed to evaluate item clarity, suitability, and initial reliability. Subsequent item analysis was conducted to determine the difficulty and discrimination indices of each test item. Items that met acceptable psychometric criteria were retained, while those that did not were revised or eliminated.

In the second stage, the validated assessment instrument was administered to 120 Grade 11 students from Betinan National High School. Standardized instructions were provided to ensure uniform administration and minimize procedural bias. Students were allotted sufficient time to complete the assessment under supervised conditions. Upon completion, all response sheets were collected, checked, encoded, and prepared for statistical analysis.

Throughout the data-gathering process, ethical considerations were strictly observed, including informed consent, voluntary participation, anonymity of respondents, and confidentiality of all collected data.

Development of the Assessment Instrument

A researcher-developed assessment instrument was utilized to measure Grade 11 learners' mastery levels in atomic structure and the periodic table of elements. Instrument development followed a systematic and theory-driven process to ensure content validity, curricular alignment, and reliability. The construction of the test was guided by the K–12 Department of Education (DepEd) Science Curriculum, focusing on competencies related to atomic models, subatomic particles, electron configuration, periodic trends, and element classification.

A table of specifications was developed to ensure proportional representation of content areas and cognitive levels based on Bloom's Taxonomy. The initial instrument consisted of fifty (50) multiple-choice items, distributed across cognitive domains: 60% assessing lower-order thinking skills (remembering and understanding), 30% assessing middle-order skills (applying and analyzing), and 10% assessing higher-order skills (evaluating and creating).

Content validation was conducted by three experts in chemistry education using standardized evaluation rubrics. The instrument obtained an overall mean rating of 3.89, interpreted as Meets Expectations, indicating that the test items were clear, relevant, and aligned with the targeted learning competencies, requiring only minimal revisions.

Following expert validation, the instrument underwent pilot testing and item analysis. Internal consistency reliability, computed using Cronbach's alpha, yielded a coefficient of 0.716, indicating acceptable reliability. The mean discrimination index of 0.299 further suggested that the items were effective in differentiating between high- and low-performing learners. Based on these analyses, twenty-six (26) items were retained, nine (9) items were revised, and fifteen (15) items were rejected. The finalized instrument consisted of a standardized 35-item multiple-choice test, which was subsequently administered during the main data collection phase.

Data Analysis

Data obtained from the standardized 35-item mastery test were analyzed using descriptive statistical techniques to determine learners' mastery levels across atomic structure and periodic table competencies. The psychometric properties established during pilot testing ensured the reliability and validity of the instrument prior to final administration. For the final dataset, internal consistency reliability yielded a Cronbach's alpha of 0.829, indicating high reliability.

Learners' scores were classified into mastery levels—not mastered, least mastered, nearly mastered, and mastered—based on predetermined criteria adapted from Department of Education standards and prior empirical studies. Frequency counts, mean scores, and percentage distributions were computed to describe performance patterns. These statistical measures formed the basis for interpreting overall mastery levels and for deriving instructional implications from the study findings.

RESULTS AND DISCUSSION

Learners' performance was analyzed to determine their level of conceptual understanding across targeted competencies. The findings provide insights into overall mastery patterns and reveal specific areas of conceptual difficulty that warrant instructional attention.

Score Distribution

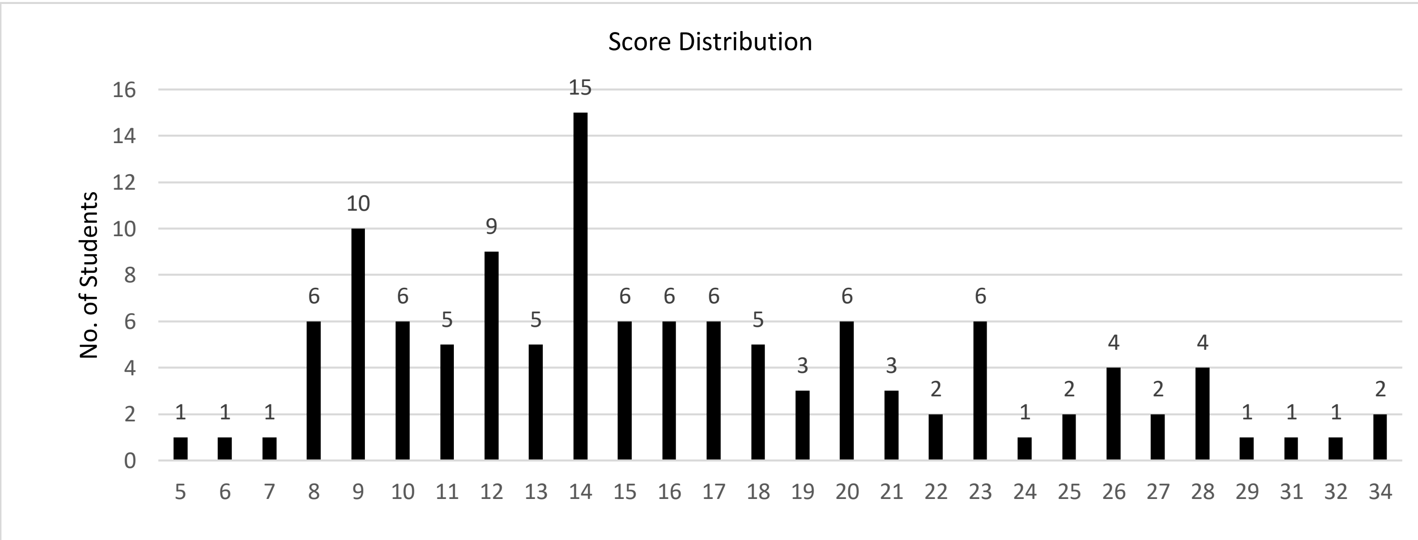

Figure 1. Score Distribution

As illustrated in Figure 1, students' scores display considerable dispersion, ranging from a minimum of 5 to a maximum of 34, indicating substantial variability in academic performance across the cohort. The mean score of 16.32 and the median score of 15 both fall within the lower segment of the possible score range, suggesting that the typical learner demonstrated limited mastery of the assessed competencies. The close correspondence between the mean and median further indicates that the distribution is not heavily influenced by extreme outliers but is instead characterized by a concentration of scores around mid-to-low values.

The score distribution exhibits positive skewness (skewness = 0.70), signifying that a relatively small proportion of students achieved higher scores, thereby extending the right tail of the distribution. In contrast, the majority of learners clustered at the lower end of the score continuum, as evidenced by the high frequency of low scores in the graphical representation. This asymmetrical pattern suggests that higher levels of achievement were attained by only a few students, while most encountered difficulties in meeting the expected performance standards.

Overall, the pronounced clustering of scores below the upper range of the assessment scale indicates widespread challenges in mastering the targeted competencies. Rather than reflecting isolated instances of low achievement, the distributional pattern points to systemic learning difficulties among the cohort. These findings underscore the necessity for instructional reinforcement, targeted remediation, and pedagogical strategies that explicitly address shared conceptual gaps and promote deeper understanding of the subject matter.

Mastery Level of Grade 11 Learners

Table 1. Mastery Level of Grade 11 Learners on Atomic Structure

Item No.	Frequency of Errors	% Error	Correct Responses	% Correct	Mastery Level
1	13	11%	107	89%	Mastered
2	61	51%	59	49%	Least Mastered
3	72	60%	48	40%	Least Mastered
4	56	47%	64	53%	Least Mastered
5	73	61%	47	39%	Not Mastered
6	59	49%	61	51%	Least Mastered
7	74	62%	46	38%	Not Mastered
12	43	36%	77	64%	Nearly Mastered
13	84	70%	36	30%	Not Mastered
14	59	49%	61	51%	Least Mastered
21	71	59%	49	41%	Least Mastered
22	64	53%	56	47%	Least Mastered
23	63	53%	57	48%	Least Mastered
24	56	47%	64	53%	Least Mastered
29	65	54%	55	46%	Least Mastered
30	69	58%	51	43%	Least Mastered
31	53	44%	67	56%	Least Mastered
32	76	63%	44	37%	Not Mastered
34	54	45%	66	55%	Least Mastered

Legend: 0 – 39% = Not Mastered 60 – 79% = Nearly Mastered

40 – 59% = Least Mastered 80 – 100% = Mastered

Table 1 presents the mastery levels of Grade 11 learners in the topic of Atomic Structure. The findings indicate that only a single assessment item achieved the Mastered classification, whereas the majority of items were categorized as either Least Mastered or Not Mastered. Notably, several items exhibited error rates exceeding 50%, reflecting a high frequency of incorrect responses and signaling substantial conceptual difficulties among learners. Only one item reached the Nearly Mastered level, suggesting limited and fragmented partial understanding of selected atomic structure concepts. Overall, the mean percentage of correct responses for Atomic Structure was 49%, which corresponds to the Least Mastered category. This result highlights pervasive gaps in learners' conceptual understanding of fundamental atomic principles and underscores the need for targeted instructional interventions to address these deficiencies.

Table 2. Mastery Level of Grade 11 Learners on Periodic Table of Elements

Item No.	Frequency of Errors	% Error	Correct Responses	% Correct	Mastery Level
8	41	34%	79	66%	Nearly Mastered
9	57	48%	63	53%	Least Mastered
10	85	71%	35	29%	Not Mastered
11	62	52%	58	48%	Least Mastered
15	75	63%	45	38%	Not Mastered
16	64	53%	56	47%	Least Mastered
17	72	60%	48	40%	Least Mastered
18	66	55%	54	45%	Least Mastered
19	71	59%	49	41%	Least Mastered
20	71	59%	49	41%	Least Mastered
25	65	54%	55	46%	Least Mastered
26	83	69%	37	31%	Not Mastered
27	61	51%	59	49%	Least Mastered
28	69	58%	51	43%	Least Mastered
33	54	45%	66	55%	Least Mastered
35	59	49%	61	51%	Least Mastered

Legend: 0 – 39% = Not Mastered 60 – 79% = Nearly Mastered

40 – 59% = Least Mastered 80 – 100% = Mastered

Table 2 presents the mastery levels of Grade 11 learners in the Periodic Table of Elements. Consistent with the findings for Atomic Structure, the majority of assessment items were classified as either Least Mastered or Not Mastered, with only one item attaining the Nearly Mastered level. Several items registered high error rates, with some exceeding 60%, indicating pronounced difficulties in understanding and applying concepts related to periodic properties, periodic trends, and element classification. The overall mean percentage of correct responses for this domain was 45%, which falls within the Least Mastered category. These results suggest substantial deficiencies in learners' conceptual grasp of periodicity and reinforce evidence that abstract representations and trend-based reasoning pose significant challenges in secondary chemistry education.

Table 3. Average Mastery Levels

Topic	**Average % Correct**	**Mastery Level**
Atomic Structure	49%	Least Mastered
Periodic Table of Elements	45%	Least Mastered
OVERALL	**47%**	**Least Mastered**

As summarized in Table 3, the overall mastery level across both topics was 47%, which is classified as Least Mastered.The persistently low mastery levels observed in Atomic Structure indicate that Grade 11 learners experience considerable difficulty in understanding concepts that operate at the submicroscopic level. Although Item 1 was classified as Mastered, its relatively high performance likely reflects learners' familiarity with recall-based or definition-oriented questions rather than a robust conceptual understanding. In contrast, the high error rates recorded across the majority of items—particularly those exceeding 50%—suggest substantial challenges in comprehending abstract concepts such as atomic structure, electron arrangement, and the interpretation of atomic models. These topics require learners to mentally visualize entities and processes that are not directly observable, thereby increasing cognitive demand. As noted by Moneteringtyas et al. (2025), misconceptions in atomic structure persist when learners fail to construct accurate mental models that meaningfully connect symbolic representations (e.g., diagrams and formulas) with underlying conceptual explanations. Consequently, students often rely on rote memorization of isolated facts rather than developing an integrated understanding of relationships among subatomic particles, atomic models, and chemical behavior. This fragmented knowledge base restricts learners' ability to transfer atomic concepts across contexts, which is reflected in the predominance of Least Mastered and Not Mastered classifications.

Similarly, the low mastery levels observed in the Periodic Table of Elements suggest that learners encounter substantial difficulty in interpreting periodic trends and relating them to atomic structure. Although Item 8 reached the Nearly Mastered level, the majority of items exhibited high error frequencies, indicating that learners possess only superficial familiarity with periodic properties. These findings imply that students may recognize observable patterns in the periodic table but lack the conceptual foundation required to explain the underlying causes of these trends. Chowdhury (2022) emphasized that learners frequently depend on surface-level heuristics—such as assuming monotonic increases or decreases across periods or groups—without grounding their reasoning in fundamental concepts such as atomic radius, effective nuclear charge, and electron configuration. Such misconceptions impede learners' ability to apply periodic knowledge to problem-solving tasks, resulting in persistent errors across assessment items.

The overall mastery level of 47%, as presented in Table 3, further underscores the magnitude of learners' conceptual difficulties across both Atomic Structure and the Periodic Table of Elements. Given that these topics serve as foundational prerequisites for more advanced chemistry concepts, limited mastery at this stage is likely to negatively affect learners' performance in subsequent topics. Consistent with these findings, Baigan et al. (2025) identified atomic structure and periodicity as among the least mastered domains in secondary chemistry education. These challenges are frequently attributed to learners' inability to integrate macroscopic observations, microscopic explanations, and symbolic representations—a well-documented issue in chemistry education research. When instructional practices fail to explicitly address these representational connections, students are more likely to retain misconceptions and resort to rote learning strategies.

Taken collectively, the predominance of Least Mastered and Not Mastered classifications across both content areas highlights the need for instructional approaches that extend beyond traditional lecture-based methods. Pedagogical strategies that emphasize conceptual coherence—such as the use of multiple representations, guided inquiry-based learning, and interactive visualizations—may support learners in constructing more accurate and integrated mental models of atomic and periodic concepts. Addressing these misconceptions at an early stage is essential for strengthening learners' conceptual foundations in chemistry and enhancing their readiness for higher-level topics that build upon these fundamental ideas.

CONCLUSION AND RECOMMENDATION

Aligned with the stated research objectives, this study concludes that the developed assessment instrument is a valid and effective tool for measuring learners' mastery of concepts related to atomic structure and the periodic table of elements. The findings indicate that while Grade 11 learners possess basic foundational knowledge, their conceptual understanding and ability to apply atomic and periodic principles remain limited. The generally low to moderate mastery levels observed across competencies suggest persistent difficulties in integrating abstract representations with conceptual explanations, particularly in topics requiring higher-order reasoning.

These results underscore the need for instructional approaches that move beyond procedural learning and emphasize conceptual coherence, representational integration, and analytical thinking. To address these gaps, chemistry teachers are encouraged to utilize the developed assessment tool, or comparable diagnostic instruments, as part of regular formative assessment practices to systematically monitor learners' mastery levels and identify specific misconceptions requiring targeted intervention. Greater instructional emphasis should be placed on conceptually demanding topics such as atomic number, mass number, isotopes, electron configuration, and periodic trends through the use of multiple representations, including visual models, simulations, and scaffolded problem-solving activities.

Furthermore, the integration of item analysis results into instructional planning is strongly recommended to ensure that least mastered and not mastered competencies receive focused remediation. Such data-driven instructional practices can support the design of targeted learning activities that directly address learners' conceptual weaknesses. At the institutional level, school administrators and curriculum planners should prioritize professional development programs that equip teachers with pedagogical strategies for effectively teaching abstract and quantitative chemistry concepts, particularly those involving submicroscopic and symbolic representations.

Finally, future research may extend the present study by refining the assessment instrument and employing intervention-based or longitudinal research designs to examine changes in learners' mastery over time. Such studies may also explore the effectiveness of specific instructional interventions in promoting deeper conceptual understanding of atomic structure and periodicity, thereby contributing to sustained improvements in chemistry education.

LIMITATIONS OF THE STUDY

This study focused on determining the mastery levels of Grade 11 learners in Atomic Structure and the Periodic Table of Elements. The content areas covered included subatomic particles, atomic models, electron configuration, classification of elements, and basic periodic trends, as prescribed in the senior high school chemistry curriculum.

The respondents of the study were limited to Grade 11 students from Betinan National High School, who served as the primary participants for the final data collection. In addition, a separate group of senior high school students from Fatima National High School participated in the pilot testing of the researcher-developed assessment instrument. The pilot testing respondents were utilized solely for the purposes of item analysis, reliability testing, and refinement of the assessment tool, and their data were not included in the final analysis of learners' mastery levels.

The study employed a researcher-developed multiple-choice assessment instrument and utilized descriptive statistical techniques in analyzing the data. It did not involve experimental treatments, comparison of groups, or the examination of other variables such as teaching strategies, learning styles, motivation, or attitudes toward chemistry.

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