Exploring Conceptual Difficulties in the Periodic Table of Elements: A Standardized Diagnostic Approach for Secondary Learners

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ABSTRACT

The Periodic Table of Elements is a cornerstone of chemistry education, yet secondary learners frequently exhibit persistent misconceptions and significant knowledge gaps regarding its fundamental concepts. This study sought to develop and validate a research-based diagnostic assessment tool to evaluate Grade 10 learners' content knowledge across selected Periodic Table competencies. Employing a descriptive research design, the instrument underwent rigorous expert validation, pilot testing, readability analysis, item analysis, and standardization to ensure its reliability and suitability for classroom application. The finalized diagnostic test was administered to Grade 10 learners from selected public high schools. Findings indicated that learners' overall content knowledge ranged from low to moderate, with none of the assessed competencies achieving full mastery. Among these, determining the number of protons, neutrons, and electrons emerged as the least mastered competency, followed by explaining the organization of elements and periodic trends. In contrast, tracing the historical development of the Periodic Table was the most successfully demonstrated skill, suggesting that learners perform comparatively better on descriptive, recall-based tasks than on conceptual and application-oriented challenges. These results underscore enduring conceptual difficulties in atomic structure and periodic reasoning, emphasizing the necessity for instructional strategies that promote deep conceptual understanding and analytical thinking. The validated diagnostic assessment tool provides educators with a robust and systematic means to identify learning gaps, address misconceptions, and inform targeted instructional planning in secondary chemistry education.

Keywords: Chemistry Education, Diagnostic Assessment, Grade 10 Learners, Misconceptions, Learning Gaps, Periodic Table of Elements

INTRODUCTION

Chemistry constitutes a fundamental domain of the natural sciences, concerned with the composition, structure, properties, and transformations of matter through chemical reactions (Chang, 2010; Amendolare, 2021). As a core component of science education, it plays a pivotal role in fostering learners' scientific literacy, analytical reasoning, and problem-solving competencies, which are critical for understanding natural phenomena and navigating contemporary technological applications. Despite its epistemic significance, chemistry is frequently perceived by secondary school learners as cognitively demanding and conceptually challenging. This perception is largely attributable to the abstract nature of chemical knowledge, its hierarchical and cumulative structure, and the integration of symbolic, microscopic, and mathematical representations required for meaningful understanding (Franco & Mariscal, 2015; Wu & Shah, 2004). Transitioning from observable macroscopic phenomena to submicroscopic and atomic-level explanations often induces cognitive overload, manifesting in diminished motivation, suboptimal academic performance, and the persistence of conceptual misconceptions.

Contemporary research in chemistry education underscores the importance of learner-centered, evidence-based pedagogical approaches that actively engage students. Empirical evidence demonstrates that strategies such as collaborative learning, game-based instruction, and interactive learning tasks can significantly enhance students' engagement, conceptual understanding, and problem-solving abilities (Freeman et al., 2014; Mariscal et al., 2016; Hou & Keng, 2021). These approaches highlight the necessity for instruction that is responsive to learners' pre-existing knowledge and misconceptions. However, effective instructional design relies critically on the availability of accurate diagnostic information regarding learners' conceptual status, including competencies they have mastered, partially understood, or not yet acquired.

Among the foundational topics in secondary chemistry curricula, the Periodic Table of Elements (PTE) is both central and pedagogically complex. The periodic table provides a unifying framework for organizing elements according to increasing atomic number and recurring chemical properties, thereby facilitating learners' understanding of atomic structure, element classification, periodic trends, and the prediction of chemical behavior (Ong & Linaugo, 2019; Robinson, 2019). Beyond its functional role as a reference, the periodic table embodies a conceptual model that illustrates the periodicity and structural organization of matter. Its historical evolution, from empirical classifications to Mendeleev's systematic arrangement and the modern atomic-number-based table, reflects the iterative nature of scientific inquiry (Bierenstiel & Snow, 2019; Guharay, 2021). As UNESCO (2019) asserts, the periodic table represents "more than just a guide or catalog of known atoms; it is a window to understanding the universe."

Despite its centrality, research consistently indicates that learners exhibit limited interest and conceptual understanding of periodic table concepts. Many students rely on rote memorization of element names, symbols, and groupings rather than developing a meaningful understanding of periodic relationships and trends (Alias & Ibrahim, 2019; Mulford & Robinson, 2002). Core competencies—including identification of subatomic particles, interpretation of periodic trends, comprehension of periodicity, and prediction of chemical behavior are frequently reported as least mastered in diverse educational contexts (Hadiprayitno et al., 2019; Salame et al., 2011). Franco-Mariscal et al. (2016) categorized recurring learning difficulties related to the periodic table, including persistent misconceptions, misinterpretation of classification criteria, inadequate grasp of periodicity, overreliance on memorization strategies, cognitive demands of abstract reasoning, and limitations in conventional instructional practices. Collectively, these findings suggest that learners often fail to integrate foundational concepts into a coherent and transferable cognitive framework.

In the Philippine educational context, the Department of Education has implemented a competency-based curriculum through the Most Essential Learning Competencies (MELCs), which emphasizes conceptual understanding and application rather than factual recall (Department of Education, 2020). Nonetheless, evidence indicates that many Grade 10 learners continue to encounter difficulties in mastering foundational chemistry concepts, including those related to the PTE (Viray, 2016). While several studies have examined innovative instructional strategies—such as game-based learning, visualization tools, and interactive activities—to enhance periodic table learning (Abdulrahim et al., 2021; Ahmad Anuar et al., 2021), fewer studies have systematically identified learning gaps and misconceptions through diagnostic assessment, particularly in the junior high school context.

Diagnostic assessment is integral to uncovering learners' prior knowledge, misconceptions, and least mastered competencies before or during instruction (Treagust, 1988; Black & Wiliam, 1998). Unlike summative evaluation, diagnostic assessment reveals underlying reasoning patterns and conceptual difficulties, providing teachers with actionable evidence to inform targeted instructional planning and remediation (Black & Wiliam, 2009). Despite its recognized utility, there remains a paucity of locally developed, standardized diagnostic instruments aligned with the Grade 10 Chemistry MELCs, particularly for essential PTE concepts such as subatomic particles, periodic trends, and predictive chemical behavior.

fWhile several diagnostic instruments in chemistry have been developed internationally, many are either concept-specific, context-bound, or not aligned with national curriculum standards. This study advances diagnostic assessment practice by developing a curriculum-aligned, standardized diagnostic tool explicitly mapped to the Philippine Grade 10 Chemistry MELCs for the Periodic Table of Elements. Unlike traditional achievement tests, the instrument integrates item-level diagnostic analysis to identify specific misconceptions and least mastered competencies, providing actionable data for classroom instruction. In doing so, the study contributes not only a localized assessment tool but also empirical evidence on persistent conceptual difficulties in atomic structure and periodic reasoning among secondary learners.

In response to this gap, the present study sought to develop and standardize a research-based diagnostic assessment tool on the Periodic Table of Elements. The study specifically aimed to (1) design a valid and reliable diagnostic instrument aligned with Grade 10 Chemistry competencies, (2) determine the least mastered learning competencies among Grade 10 learners, and (3) evaluate learners' content knowledge based on performance in the developed diagnostic tool. By systematically identifying conceptual gaps and misconceptions, this study aims to facilitate data-driven instruction, improve chemistry assessment practices, and contribute to the empirical literature on diagnostic assessment in secondary science education.

METHODOLOGY

2.1 Research Design

A descriptive research design incorporating instrument development and validation was employed. This design facilitated the systematic construction, validation, and standardization of a diagnostic assessment tool to identify Grade 10 learners' misconceptions and learning gaps regarding the Periodic Table of Elements. The instrument was developed in alignment with the Grade 10 Chemistry MELCs and subjected to expert validation, pilot testing, readability testing, item analysis, and reliability analysis. Descriptive statistical techniques, including mean scores and percentages, were used to evaluate learner performance and determine the least mastered competencies.

2.2 Research Participants

Participants comprised Grade 10 learners from selected public high schools in Iligan City. Pilot testing involved 144 learners across three sections to perform item analysis and refine the diagnostic instrument. For the standardization phase, the revised instrument was administered to 74 learners from three sections of a separate public high school. Inclusion criteria required learners to be officially enrolled in Grade 10, have completed instruction on the PTE, and be present during test administration. Students from other grade levels, absent learners, and those without informed consent were excluded.

Although the sample size for the standardization phase was limited, it was sufficient for preliminary validation and item-level diagnostic analysis. The primary purpose of the instrument was classroom-level diagnosis rather than large-scale generalization. Future studies may involve larger and more diverse samples to further establish normative benchmarks and external validity.

2.3 Research Instruments

The primary tool was a researcher-developed, multiple-choice diagnostic assessment instrument. Initially, the tool consisted of 50 items aligned with the Grade 10 Chemistry MELCs, covering subatomic particles, the historical development of the Periodic Table, periodic trends, and the classification and chemical behavior of elements. Item construction was guided by Bloom's Taxonomy to ensure a balanced assessment across various cognitive levels.

A Table of Specifications (TOS) was utilized to maintain content validity and cognitive representation. Three PhD-level experts in chemistry and science education conducted content validation, evaluating the tool for clarity, relevance, and curricular alignment; the instrument was subsequently revised based on their feedback. Following pilot testing with 144 learners, item analysis was performed to determine difficulty and discrimination indices. Items failing to meet established psychometric standards were either revised or removed. The final version of the instrument comprised 30 items, which were used during the standardization phase for data collection.

2.4 Data Collection

Data collection was conducted in two distinct stages: pilot testing and standardization. The pilot test involved 144 learners, with the results guiding the refinement of the instrument through item analysis. The finalized 30-

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item diagnostic tool was then administered to 74 learners via Google Forms to ensure uniform administration and automated, accurate data recording. Throughout the process, ethical standards—including informed consent and respondent confidentiality—were strictly observed.

2.5 Data Analysis

Descriptive statistics and item analysis techniques were applied to evaluate learner performance and assess the instrument's psychometric properties. Mean scores were used to describe overall content knowledge, while percentages quantified response distributions for each item and competency.

Item analysis involved calculating the difficulty index (*p*) to classify items (ranging from very difficult to easy) and the discrimination index *(D)* to evaluate the item's ability to differentiate between high- and low-performing learners. Cross-tabulation of the *p* and *D* indices informed the final decisions regarding item retention, revision, or rejection. Additionally, Cronbach's alpha was computed to determine internal consistency, with the resulting coefficient confirming that the instrument possessed acceptable reliability for diagnostic applications.

Table 1: Bases of Construction of Item Analysis Matrix

DIFFICULTY LEVEL/INDEX	DISCRIMINATION LEVEL/INDEX				
	Poor Item (<0.10)	Marginal item (0.10-0.19)	Moderately Discriminating Item (0.20-0.29)	Good Item (0.30-0.39)	Very Good Item (0.40>)
Difficult Item (0.24 or <)	Reject	Revise	Revise	Revise	Revise
Average Item (0.25-0.75)	Reject	Revise	***Retain***	***Retain***	***Retain***
Easy Item (0.76 or >)	Revise	Revise	Revise	Revise	Revise

Table 2: Discrimination index and Verbal interpretation

Discrimination Index	Verbal Interpretation
0.40 and above	Excellent item
0.30-0.39	Reasonably good
0.20-0.29	Marginal item
Below 0.19	Poor item

Table 3: Difficulty Index and Verbal Interpretation

Difficulty Index	Verbal Interpretation
0.00 – 0.20	Very Difficult
0.21 – 0.40	Difficult
0.41 – 0.60	Average
0.80 – 1.00	Very Easy

RESULTS AND DISCUSSION

3.1 Performance of the Students on the Achievement Test

A central focus of this study was the evaluation of Grade 10 learners' performance on the researcher-developed diagnostic assessment instrument targeting the Periodic Table of Elements. The analysis of test outcomes provided a comprehensive overview of students' conceptual understanding across the delineated competencies. Performance scores were systematically interpreted using established descriptors, as illustrated in Figure 1, to identify the specific topics and competencies that learners had least mastered, thereby revealing critical areas of conceptual difficulty within the subject domain.

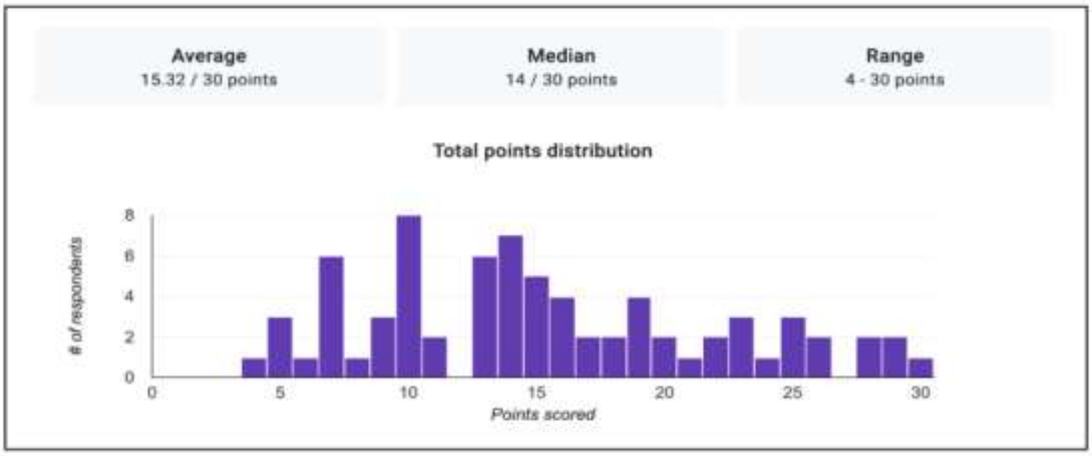

Figure 2. Total Points Distribution of Grade 10 Learners

Figure 2 presents the total score distribution of Grade 10 learners on the standardized 30-item diagnostic assessment of the Periodic Table of Elements. Learners' scores ranged from 4 to 30, with a mean of 15.32 and a median of 14, indicating that, on average, students correctly answered approximately half of the items, reflecting a moderate overall level of content knowledge. The slightly lower median and the positively skewed distribution suggest that a minority of learners achieved high scores, while most clustered in the lower to mid-range (approximately 8–18 points), revealing partial mastery of essential concepts such as subatomic particles, periodic trends, and chemical behavior. This spread underscores the diagnostic utility of the instrument, effectively differentiating among learners with varying levels of conceptual understanding and highlighting those requiring targeted instructional support.

Item-level analysis across four competencies—(1) determining the number of protons, neutrons, and electrons in atoms, (2) tracing the historical development of the periodic table, (3) explaining the organization and periodic trends of elements, and (4) predicting chemical behavior revealed notable variability in mastery. Learners performed relatively well on items addressing descriptive and historical aspects, such as the development of the periodic table, whereas conceptual and application-based items, particularly those involving atomic structure, subatomic particles, and periodic trends, were answered less successfully. Misconceptions were prevalent in

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differentiating atomic number from mass number and interpreting periodic patterns, suggesting that learners often maintain fragmented or superficial conceptual frameworks.

Collectively, these findings indicate that while learners exhibit foundational familiarity with the periodic table, their conceptual understanding is inconsistent, with several competencies below the expected mastery threshold. The results affirm the diagnostic assessment tool's effectiveness in identifying the least mastered competencies and learning gaps, thereby providing evidence to guide targeted instructional interventions aimed at enhancing Grade 10 learners' conceptual comprehension in chemistry.

Least Mastered Competencies

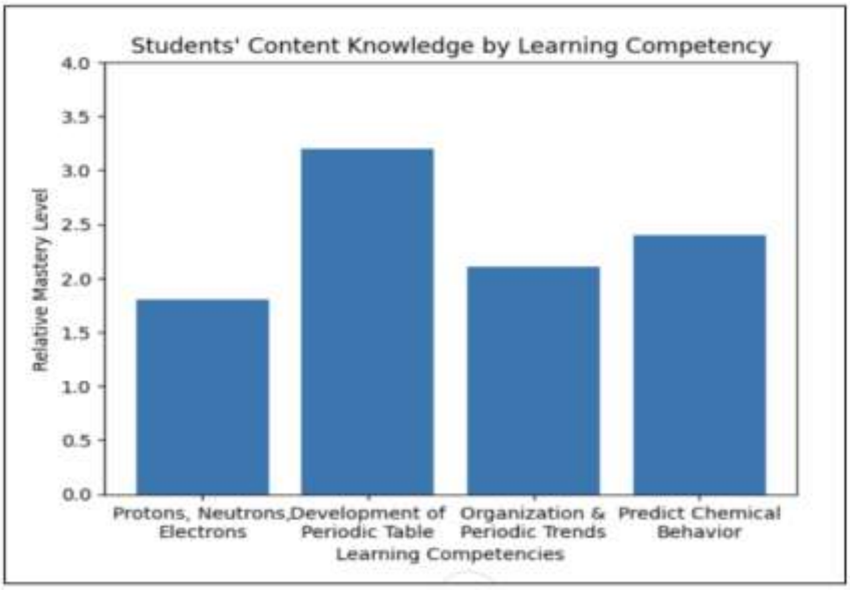

Figure 3. Ranking of Least Mastered Competencies

The results of the study indicate that learners' overall content knowledge in chemistry ranged from low to moderate, suggesting that while they possess basic factual understanding, substantial learning gaps and misconceptions remain. Performance across the four assessed competencies revealed uneven mastery of Periodic Table concepts, reflecting both conceptual and procedural difficulties that extend beyond mere recall.

Among the competencies assessed, determining the number of protons, neutrons, and electrons in an atom was the least mastered. Learners encountered considerable difficulty in computing subatomic particles using atomic and mass numbers, as evidenced by low correct response rates and recurring misconceptions. This finding underscores persistent weaknesses in foundational atomic structure concepts, which serve as a critical prerequisite for understanding more advanced chemistry topics.

Competency in explaining the organization and periodic trends of elements was also demonstrated low mastery level. Learners struggled to articulate periodic relationships, including electronegativity, reactivity, and group–period distinctions. Such difficulties suggest that challenges lie primarily in conceptual reasoning and abstract thinking rather than simple memorization, highlighting the cognitive demands of understanding periodic trends.

In contrast, learners exhibited relatively higher mastery in using the periodic table to predict the chemical behavior of elements. Nevertheless, misconceptions persisted when students applied periodic trends to novel or unfamiliar situations, indicating incomplete conceptual transfer. The highest level of mastery was observed in tracing the historical development of the periodic table, with learners demonstrating stronger performance on descriptive, recall-based knowledge, such as the contributions of Mendeleev and Moseley.

Collectively, these findings reveal pronounced disparities in competency across the assessed areas, with foundational atomic structure concepts emerging as the most challenging. Although learners demonstrate familiarity with the Periodic Table, significant gaps persist in both conceptual understanding and practical application. These results underscore the need for instructional approaches that prioritize conceptual reasoning, application-based learning, and the strategic use of diagnostic assessment data to identify and remediate learners' misconceptions effectively.

CONCLUSION AND RECOMMENDATION

This study developed and standardized a curriculum-aligned diagnostic assessment tool to evaluate Grade 10 learners' understanding of the Periodic Table of Elements and to identify their least mastered competencies. Through expert validation, pilot testing, item analysis, and reliability testing, the instrument demonstrated acceptable psychometric quality and diagnostic value, supporting its use for classroom-based assessment and instructional planning.

Findings revealed that learners' overall content knowledge ranged from low to moderate, with uneven mastery across the assessed competencies. The least mastered competency was determining the number of protons, neutrons, and electrons in a particular atom, indicating persistent difficulties with foundational atomic structure concepts and the interpretation of atomic and mass numbers. Learners also showed weak conceptual understanding of the organization of elements and periodic trends, particularly when required to explain trend directions and underlying periodic patterns. These results suggest that students struggle more with abstract reasoning and conceptual explanation than with factual recall.

In contrast, learners demonstrated relatively higher performance in using the periodic table to predict chemical behavior, although misconceptions remained when applying periodic trends to unfamiliar contexts. The highest level of mastery was observed in tracing the historical development of the periodic table, confirming that descriptive and recall-based content is more accessible to learners than conceptually demanding tasks. Collectively, these findings align with prior research indicating that difficulties in atomic structure and periodic reasoning often stem from fragmented conceptual frameworks rather than a lack of exposure to content.

From an instructional perspective, the results suggest that conventional sequencing and teaching approaches may insufficiently support conceptual integration of atomic structure and periodicity. The diagnostic data generated by the developed instrument provide teachers with actionable insights that can inform targeted remediation, conceptual re-teaching, and the use of visual models, guided reasoning tasks, and formative feedback. Rather than serving as a summative measure, the instrument is best utilized as an assessment-for-learning tool to guide instruction and address misconceptions early.

It is therefore recommended that chemistry teachers integrate diagnostic assessment into regular classroom practice, particularly before or during instruction on the Periodic Table of Elements. School administrators may support this integration through professional development focused on interpreting diagnostic data and implementing conceptually driven interventions. Curriculum developers are encouraged to reinforce atomic structure and periodic reasoning within the Grade 10 chemistry sequence to ensure conceptual continuity.

Future research may extend the use of the developed diagnostic instrument to larger and more diverse learner populations or employ it as a baseline measure in intervention-based or technology-enhanced studies aimed at improving students' conceptual understanding of the Periodic Table of Elements.

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