Assessing Grade 11 Learners' Mastery of Chemical Bonding: Development of a Standardized Tool and Analysis of Study Habits

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ABSTRACT

Chemical bonding constitutes a foundational concept in General Chemistry, essential for understanding the structure and properties of matter. Despite its importance, it remains one of the least mastered topics among secondary learners, largely due to its abstract, multi-representational nature. The present study aimed to develop and validate a standardized assessment tool to measure Grade 11 learners' mastery of chemical bonding and to examine their study habits in relation to learning outcomes. Employing a predominantly quantitative research design supplemented with qualitative insights, the study involved the systematic development, validation, and implementation of a chemical bonding assessment aligned with Bloom's Taxonomy. Pilot testing with 150 Grade 11 learners was conducted, followed by item analysis and reliability testing, resulting in a standardized 39-item instrument. The finalized tool demonstrated acceptable internal consistency (Cronbach's $\alpha = 0.80$) and was subsequently administered to 117 Grade 11 learners across the Academic and Technical–Professional tracks. Descriptive analyses revealed that the majority of learners did not achieve the mastery threshold, with only four respondents attaining a passing score. The highest levels of mastery were observed in tasks involving identification of chemical bond types, whereas the lowest performance emerged in competencies requiring prediction of compound types based on bonding-related data. Complementary qualitative findings from an open-ended study habits questionnaire indicated that learners employed a range of self-regulated learning strategies; however, discrepancies persisted between study effort and the attainment of deep conceptual understanding. Collectively, these results underscore the critical need for validated diagnostic assessment tools and instructional interventions that simultaneously foster conceptual comprehension and effective learning strategies, thereby enhancing learners' mastery of chemical bonding.

Key Words: Chemical Bonding, General Chemistry, Mastery Assessment, Senior High School, Study Habits

INTRODUCTION

Chemical bonding is widely recognized as one of the most conceptually demanding topics in General Chemistry because it requires learners to meaningfully integrate multiple levels of chemical representation. Students must simultaneously connect submicroscopic explanations involving electrons, ions, and molecular interactions with symbolic forms such as Lewis structures, chemical formulas, and equations, as well as with macroscopic properties including melting point, electrical conductivity, and chemical reactivity. This representational complexity creates fertile ground for the development of misconceptions—alternative explanatory frameworks that appear internally logical to learners but diverge from accepted scientific models. Such misconceptions are particularly persistent in chemistry due to the abstract, invisible, and highly symbolic nature of its core concepts (Tümay, 2016; Üce & Ceyhan, 2019). A recent systematic review of chemistry misconception research further underscores that misunderstandings in foundational topics, including chemical bonding, often propagate into subsequent areas of instruction, resulting in cumulative conceptual gaps that undermine long-term conceptual coherence and overall mastery (Suparman et al., 2024)

Within the context of this thesis, chemical bonding is conceptualized as a gateway concept in chemistry learning. Inadequate mastery of bonding principles compromises students' understanding of molecular geometry, polarity, intermolecular forces, and chemical reactions, frequently leading to fragmented knowledge structures and reliance on rote memorization rather than meaningful learning. Prior research has demonstrated that when learners fail to construct robust mental models of bonding, their subsequent reasoning across chemistry topics becomes increasingly superficial and rule-based, rather than conceptually grounded (Tümay, 2016; Suparman et al., 2024).

Empirical evidence from chemical education research consistently indicates that upper secondary students experience substantial difficulties in distinguishing among ionic, covalent, and metallic bonding; interpreting electronegativity differences and bond polarity; and explaining the relationship between bonding type and observable physical properties. Tsaparlis et al. (2018) documented recurring conceptual challenges among upper secondary learners, revealing that even when students can correctly apply algorithmic rules, they frequently misinterpret fundamental ideas such as electron transfer versus electron sharing, the conceptual meaning of the octet rule, and the structural implications of different bonding interactions. Complementary findings from diagnostic studies employing two-tier assessment instruments—which evaluate both answer selection and underlying reasoning—demonstrate that misconceptions in chemical bonding remain prevalent among Grade 10 learners. These studies further reveal that correct responses may conceal flawed reasoning, thereby obscuring persistent conceptual misunderstandings (Fadillah & Salirawati, 2018). Collectively, these findings align with broader analyses suggesting that chemistry misconceptions are not trivial errors but rather robust cognitive frameworks shaped by prior instruction, everyday language usage, and oversimplified heuristic rules commonly presented in textbooks (Üce & Ceyhan, 2019; Tümay, 2016).

Beyond conceptual challenges, students' study habits constitute an additional factor that may influence the development, persistence, or remediation of misconceptions in complex chemistry topics. Study habits encompass a range of learning behaviors, including time management, regularity of review, note-taking strategies, self-assessment practices, and utilization of learning resources. Previous research indicates that effective study habits are positively associated with academic achievement, whereas inconsistent or ineffective habits are linked to weaker learning outcomes (Rabia et al., 2017). Similarly, investigations into study attitudes and habitual learning practices suggest that academic performance is not solely a function of cognitive ability but is also shaped by how learners engage with instructional tasks over time (Tus, 2020). In the case of chemical bonding—where conceptual understanding requires iterative practice, representational coordination, and systematic correction of erroneous ideas—study habits may partially account for variations in mastery levels among learners. Students who engage in sustained retrieval practice, problem-solving, and reflective error analysis are more likely to restructure misconceptions, whereas those who rely primarily on short-term memorization may reinforce incorrect mental models and exhibit enduring learning gaps (Rabia et al., 2017; Tus, 2020).

Consequently, identifying and mapping learning gaps in chemical bonding is a critical step toward the development of targeted, evidence-based instructional interventions. Prior studies have demonstrated that instruction explicitly aligned with diagnosed misconceptions and least mastered competencies leads to significant gains in student understanding. For example, Rosal et al. (2022) reported that the implementation of Electronic Strategic Intervention Materials (E-SIM) substantially improved the least mastered competencies of Grade 11 students in General Chemistry, underscoring the value of diagnostic-driven and remediation-focused instructional design. When such interventions are informed not only by conceptual deficiencies but also by learners' study habits, they hold greater potential to facilitate both conceptual change and the cultivation of effective, self-regulated learning behaviors.

1.1 Statement of the Problem

Chemical bonding is a fundamental concept in General Chemistry; however, numerous studies have shown that students consistently experience learning difficulties and hold persistent misconceptions in this area.

Common difficulties include misunderstandings related to electron transfer and sharing, bond polarity, and the relationship between bonding and material properties (Tümay, 2016; Üce & Ceyhan, 2019; Tsaparlis et al., 2018). Such misconceptions often reflect superficial understanding and lead to learning gaps that hinder students' mastery of more advanced chemistry concepts (Fadillah & Salirawati, 2018; Suparman et al., 2024).

Beyond conceptual challenges, students' study habits play a crucial role in academic performance. Research indicates that effective study habits promote deeper conceptual understanding, whereas poor or inconsistent habits may contribute to lower mastery levels, particularly in cognitively demanding subjects such as chemistry (Rabia et al., 2017; Tus, 2020). Despite this, limited studies have explored the relationship between students' study habits and their mastery of chemical bonding, especially in terms of identifying specific learning gaps.

To address these concerns, the present study aims to develop and validate a reliable assessment instrument for measuring mastery of chemical bonding concepts in Senior High School General Chemistry. Specifically, it seeks to determine the least mastered competencies of Grade 11 learners in chemical bonding and to examine the relationship between their study habits and learning outcomes in this topic.

1.2 Objectives of the Study

This study aims to develop a valid and standardized assessment instrument to identify the least mastered competencies in Senior High School General Chemistry, with particular focus on chemical bonding. Specifically, the study aims to:

1. Develop and validate a standardized assessment instrument for measuring learners' mastery of chemical bonding concepts in General Chemistry.

2. Determine the level of mastery of Grade 11 learners in the following chemical bonding content areas:

   a. Types of chemical bonds and compounds

   b. Physical properties of ionic, covalent, and metallic substances

   c. Prediction of compound type based on bonding-related data

   d. Formation of ions and bonding particles

3. Assess the study habits of Grade 11 learners in learning General Chemistry.

METHODOLOGY

This study adopts a quantitative-dominant research design with qualitative support. The primary methodological orientation is quantitative, emphasizing the systematic development, validation, and administration of a standardized assessment instrument designed to measure the mastery level of Grade 11 learners in chemical bonding and to examine their study habits. Quantitative data were generated from learners' scores on the chemical bonding assessment tool and were subjected to appropriate statistical analyses to determine mastery levels, item performance, and overall instrument reliability.

To complement and enrich the quantitative results, qualitative data were collected through researcher-developed open-ended questions embedded within the study habits questionnaire. These open-ended items enabled learners to articulate their reasoning processes, describe learning difficulties, and explain their study practices using their own language. The qualitative responses provided contextual depth and explanatory insight into learners' misconceptions, reasoning patterns, and learning behaviors that may not be fully captured through numerical scores alone, thereby strengthening the interpretive value of the findings.

2.1 Research Setting

The study was conducted in two public secondary schools in Misamis Occidental, Philippines, both of which offer Senior High School programs under the Academic Track and the Technical–Professional (TechPro) Track. These schools were purposively selected due to their adequate enrollment of Grade 11 learners and the diversity of tracks represented, which was essential for both pilot testing and full-scale implementation of the assessment instrument.

The pilot testing phase was carried out in one public secondary school within the province that offers both the Academic and TechPro tracks. This setting ensured the inclusion of learners from varied academic backgrounds, a necessary condition for conducting meaningful item analysis and establishing the initial reliability of the assessment tool.

The actual implementation phase was conducted in a different public secondary school within the same province. This school was similarly selected based on its sufficient population of Grade 11 learners across multiple tracks, making it suitable for administering the finalized 39-item standardized assessment tool under conditions representative of the target population.

2.2 Participants

The participants of the study were Grade 11 Senior High School learners enrolled in public secondary schools in Misamis Occidental, Philippines. The respondents came from both the Academic Track and the Technical–Professional (TechPro) Track, ensuring representation of learners with varied academic orientations and learning contexts.

This study employed 3:1 respondent-to-item ratio, which two groups of participants were involved at different phases of the study. During the pilot testing phase, a total of 150 Grade 11 learners participated in the initial administration of the 50-item Chemical Bonding Assessment Tool. These participants were selected through purposive sampling, based on their enrollment in General Chemistry and availability during the pilot implementation period. Learners who participated in the pilot test were excluded from the actual implementation to avoid test familiarity and potential bias.

For the actual implementation phase, the finalized 39-item standardized assessment tool was administered to 117 Grade 11 learners from a different public secondary school within the same province. These participants were likewise selected using purposive sampling, with inclusion criteria requiring current enrollment in General Chemistry and consent to participate in the study. The selected learners represented different tracks under the Academic and TechPro tracks.

Ethical safeguards were strictly observed. Permissions were secured from school administrators and subject teachers prior to data collection. Participation was voluntary, and respondents were informed of the purpose of the study. No identifying information was collected, and all data were used solely for research purposes.

2.3 Research Instruments

To ensure the adequacy of data for instrument development and validation, the study followed a respondent-to-item ratio of 3:1, which is commonly recommended in educational measurement for item analysis and reliability estimation.

The initial version of the Chemical Bonding Assessment Tool consisted of a 50-item test, aligned with the Most Essential Learning Competencies (MELCs) covering key topics in chemical bonding. The assessment tool was then subjected to validation process by the three content and pedagogy experts, evaluating the content validity, clarity, difficulty, quality of distractors, alignment with learning objectives, and format consistency.

Additionally, it also underwent readability testing to ensure the accessibility of the assessment tool to the targeted participants. After the validation and readability test of the assessment tool, it was subjected to pilot testing with 150 Grade 11 learners. The initial version covered the identified content areas, including types of chemical bonds and compounds, physical properties of ionic, covalent, and metallic substances, prediction of compound type based on bonding related data, and formation of ions and bonding particles. This version was used during the pilot testing phase to conduct item analysis and determine the reliability of the instrument. Items that failed to meet acceptable psychometric criteria were revised or discarded based on established validation standards.

Following the pilot testing and item analysis, the instrument was refined and finalized into a 39-item standardized assessment tool. Content and pedagogical validation were conducted by subject-matter and pedagogy experts to ensure alignment with the General Chemistry curriculum, clarity of items, and appropriateness for the cognitive level of Grade 11 learners. The actual implementation of the 39-iem standardized assessment tool was participated by the 117 Grade 11 learners across tracks.

Table 1: Mean Rating Descriptor on the Assessment Tool Validation

Scale/Range	Decision	Description
1-1.19	REJECT	Not acceptable. Revamp the test items.
2.0-2.9	MODIFY	Acceptable, but requires slight revision.
3.0-4.0	ACCEPT	Acceptable, no modification needed.

2.4 Statistical Tools

Several statistical tools were employed to analyze and interpret the data generated in this study. Descriptive statistics, specifically the mean, were used to determine the average mastery level of Grade 11 learners in chemical bonding and to summarize overall performance across the identified content areas of the assessment instrument. The mean scores provided a quantitative basis for comparing learners' levels of conceptual understanding and identifying general trends in mastery.

Percentage distribution was utilized to describe the proportion of learners falling within specific mastery levels and to identify the least mastered competencies in chemical bonding based on performance across each content domain. This approach facilitated a clearer interpretation of learning gaps by highlighting content areas that require targeted instructional intervention.

In addition, item analysis was conducted during the pilot testing phase to evaluate the psychometric quality of the assessment tool. This analysis involved the computation of item difficulty indices and item discrimination indices to determine the extent to which individual test items appropriately reflected varying levels of learner mastery and effectively differentiated between high- and low-performing students. The results of the item analysis served as the empirical basis for the revision, refinement, and final selection of test items included in the standardized assessment instrument.

Table 2: Difficulty and Discrimination Indices Scale

Range/Scale	Difficulty Index	Discrimination Index
0.86 and above	Very Easy	To be Discarded
0.71-0.85	Easy	To be Revised

0.30-0.70	Moderate	To be Retained
0.15-0.29	Difficult	To be Revised
0.14 and below	Very Difficult	To be Discarded

Adopted from Hopkins and Antes

Table 3: DepEd Mastery Level Standard Scale

Mastery Level	Standard Scale
Mastered	80% - 100%
Nearly Mastered	60%-79%
Least Mastered	40%-59%
Not Mastered	0-39%

2.5 Ethical Considerations

Ethical standards governing educational research involving human participants were strictly observed throughout the conduct of this study. Prior to data collection, formal approval was obtained from the Schools Division Superintendent (SDS), school principals, and subject teachers concerned. The objectives, procedures, and scope of the study were clearly explained to all participants to ensure informed participation. Participation was strictly voluntary, and learners were informed of their right to withdraw from the study at any stage without academic consequences or penalty.

Participants' confidentiality and anonymity were safeguarded by excluding all personally identifying information from the research instruments, datasets, and reports. All data collected were used exclusively for research purposes and were treated with strict confidentiality. Given that student participants constitute a vulnerable population, additional safeguards were implemented to protect their welfare, including minimizing risk, ensuring non-coercive participation, and maintaining transparency throughout the research process.

Teachers who assisted in the administration of the instruments were provided with a modest token and snacks, while student participants received snacks as a form of appreciation. These provisions were non-monetary, non-coercive, and did not influence participants' decision to take part in the study. The researcher declared no conflict of interest and ensured that all ethical procedures adhered to institutional and professional research standards. All research data were securely stored in password-protected digital files and locked physical storage, accessible only to the researcher.

RESULTS AND DISCUSSION

3.1 Standardized Assessment Tool

The results of the item analysis conducted during the pilot testing phase informed the refinement of the chemical bonding assessment instrument. Of the initial 50 test items, 25 items were retained without modification, as they demonstrated acceptable levels of item difficulty and satisfactory discrimination indices, indicating their effectiveness in distinguishing between high- and low-performing learners.

A total of 14 items were identified for revision due to issues such as extreme difficulty or ease, as well as marginal discrimination values. Despite these limitations, these items were considered potentially viable after refinement and were therefore revised rather than discarded. In contrast, 11 items were eliminated from the instrument because they exhibited very poor discrimination indices, including negative values, suggesting that they failed to function appropriately as measures of learners' mastery of chemical bonding concepts.

The outcomes of the item analysis served as the empirical basis for retaining strong items, revising borderline items, and removing ineffective ones. As a result of this systematic refinement process, the finalized version of the standardized assessment tool comprised 39 items, reflecting improved content validity, measurement reliability, and overall psychometric quality. This finalized instrument was subsequently used in the actual implementation phase to assess Grade 11 learners' mastery of chemical bonding.

Table 4: Summary of the Item Analysis

Item No.	Difficulty Index	Interpretation	Discrimination Index	Remarks
1	0.653	Moderate	0.537	Retain
2	0.820	Easy	0.415	Retain
3	0.293	Difficult	0.244	Revise
4	0.707	Easy	0.341	Retain
5	0.500	Moderate	0.366	Retain
6	0.753	Easy	0.317	Retain
7	0.327	Moderate	0.463	Retain
8	0.660	Moderate	0.390	Retain
9	0.500	Moderate	0.073	Discard
10	0.080	Very Difficult	-0.073	Discard
11	0.207	Difficult	0.390	Retain
12	0.293	Difficult	0.244	Revise
13	0.193	Difficult	0.293	Revise
14	0.200	Difficult	0.171	Revise
15	0.287	Difficult	0.220	Revise
16	0.280	Difficult	0.244	Revise
17	0.527	Moderate	0.707	Revise
18	0.767	Easy	0.439	Retain
19	0.580	Moderate	0.585	Retain

20	0.900	Very Easy	0.244	Revise
21	0.773	Easy	0.561	Retain
22	0.780	Easy	0.610	Retain
23	0.227	Difficult	0.098	Discard
24	0.333	Moderate	0.439	Retain
25	0.333	Moderate	0.220	Revise
26	0.573	Moderate	0.659	Retain
27	0.800	Easy	0.463	Retain
28	0.287	Difficult	-0.073	Discard
29	0.193	Difficult	-0.073	Discard
30	0.713	Easy	0.512	Retain
31	0.707	Easy	0.683	Retain
32	0.660	Moderate	0.659	Retain
33	0.413	Moderate	0.341	Retain
34	0.660	Moderate	0.805	Revise
35	0.593	Moderate	0.268	Revise
36	0.127	Very Difficult	0.049	Discard
37	0.673	Moderate	0.805	Revise
38	0.653	Moderate	0.146	Discard
39	0.567	Moderate	0.707	Revise
40	0.167	Difficult	0.171	Revise
41	0.507	Moderate	0.683	Retain
42	0.667	Moderate	0.610	Retain
43	0.227	Difficult	-0.220	Discard
44	0.220	Difficult	-0.122	Discard
45	0.707	Easy	0.634	Retain
46	0.660	Moderate	0.610	Retain

47	0.200	Difficult	-0.220	Discard
48	0.173	Difficult	-0.122	Discard
49	0.593	Moderate	0.366	Retain
50	0.493	Moderate	0.561	Retain

Interpretation: ≥0.86 (Very Easy, Discard) 0.71-0.85 (Easy, Revise) 0.30-0.70 (Moderate, Retain)

0.15-0.29 (Difficult, Revise) ≤0.14 (Very Difficult, Discard)

3.2 Reliability of the Assessment Tool

Table 5 presents the results of the reliability analysis conducted during the pilot testing phase of the chemical bonding assessment tool. The analysis yielded a Cronbach's alpha (α) coefficient of 0.82, indicating good internal consistency of the instrument. This finding suggests that the test items function cohesively and consistently measure the same underlying construct, namely learners' mastery of chemical bonding concepts.

Table 6 reports the reliability results obtained during the actual implementation of the finalized and standardized Chemical Bonding Assessment Tool. The computed Cronbach's alpha (α) value of 0.80 likewise indicates good internal consistency, based on widely accepted reliability benchmarks. The slight variation between the pilot testing and actual implementation reliability coefficients remains within acceptable limits and reflects the stability of the instrument across different samples.

Collectively, these results provide strong empirical evidence that the assessment tool demonstrates reliable measurement properties and is suitable for use in evaluating Grade 11 learners' mastery of chemical bonding concepts in both research and instructional contexts.

Table 5: Reliability Test Result Statistics (Pilot Testing)

	Mean	**SD**	**Cronbach's α**
scale	0.484	0.143	0.82
Reliability Interpretation: α ≥0.9 (Excellent) α=0.8-0.89 (Good) α=0.70-0.79 (Acceptable) α=0.60-0.69 (Questionable) α=0.50-0.59 (Poor) α<0.50 (Unacceptable)			

Table 6: Reliability Test Result Statistics (Actual Implementation)

	Mean	**SD**	**Cronbach's α**
scale	0.486	0.174	0.80
Reliability Interpretation: α ≥0.9 (Excellent) α=0.8-0.89 (Good) α=0.70-0.79 (Acceptable) α=0.60-0.69 (Questionable) α=0.50-0.59 (Poor) α<0.50 (Unacceptable)			

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3.3 Learners' Performance in the Standardized Assessment Tool

Learners' performance was evaluated using the standardized Chemical Bonding Assessment Tool, a 39-item instrument administered to 117 Grade 11 learners (N = 117) from different academic tracks during the actual implementation phase of the study. The assessment was designed to measure learners' mastery of key chemical bonding concepts in General Chemistry.

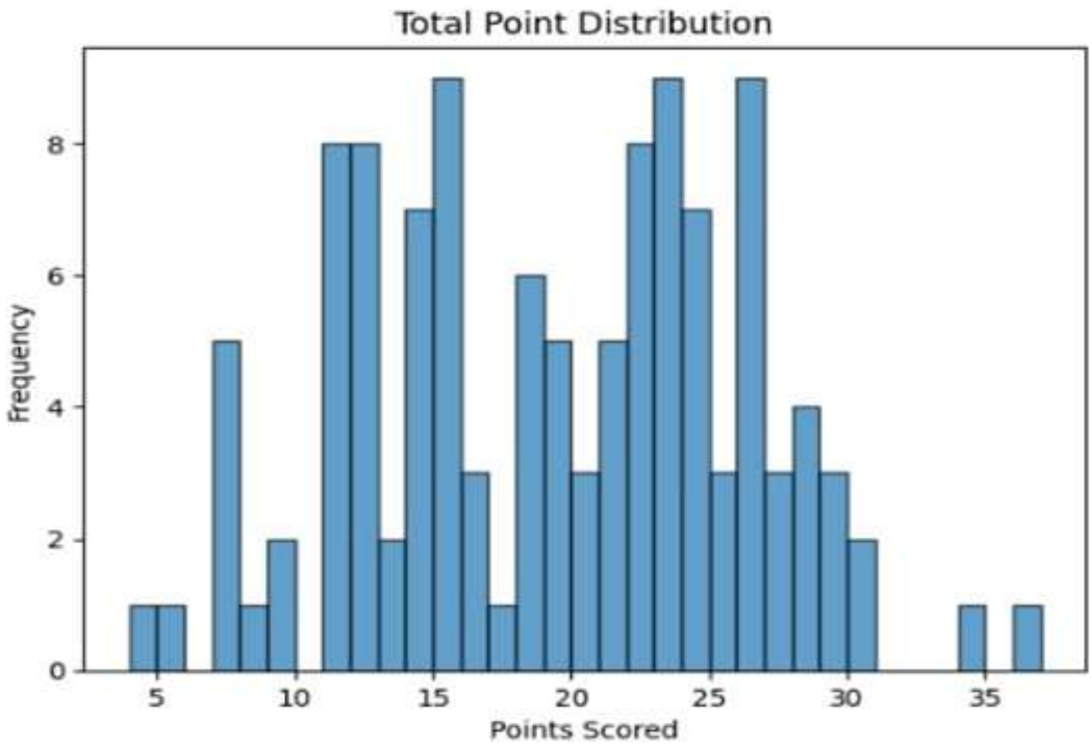

Figure 1: Total Points Distribution

Figure 1 illustrates the distribution of raw scores obtained by the respondents in the standardized Chemical Bonding Assessment Tool. The x-axis represents the range of points scored, while the y-axis indicates the frequency of learners within each score range. The distribution demonstrates a broad dispersion of scores, with a noticeable concentration between 15 and 25 points. The highest frequencies are observed at approximately 20 and 25 points, indicating that a substantial proportion of learners clustered around these score values and exhibited comparable levels of performance.

Scores at the lower extreme (approximately 5–10 points) and the upper extreme (30–35 points) occur with relatively low frequency, suggesting that very low and very high performances were uncommon within the sample. This pattern indicates that the majority of learners demonstrated low to moderate mastery, while only a small number exhibited either severe conceptual difficulty or relatively strong understanding of chemical bonding concepts.

3.4 Mastery Level of Grade 11 Learners in General Chemistry (Chemical Bonding)

This section examines the mastery level of Grade 11 learners in General Chemistry, with specific emphasis on the topic of chemical bonding. Analyzing mastery levels provides critical insight into learners' conceptual strengths as well as competencies that require targeted instructional support. Such analysis is essential for identifying persistent learning gaps and informing evidence-based intervention strategies.

As presented in Table 7, learners' mean percentage and mastery levels are summarized across the identified learning competencies related to chemical bonding in General Chemistry. The results highlight varying degrees of mastery across competencies, revealing patterns of conceptual understanding and difficulty within the domain. These findings serve as the basis for identifying least mastered competencies, which are discussed in relation to learners' overall performance and are used to guide the development of focused remediation and instructional interventions.

Table 7: Mastery Level of the Grade 11 Learners in Chemical Bonding

Learning Competency/Topic	Mean Percentage	Mastery Level
Types of Chemical Bonds and Compounds	60%	Nearly Mastered
Physical Properties of Ionic, Covalent, Metallic	53%	Least Mastered
Predicting Compound Type Based on Bonding Data	46%	Least Mastered
Formation of Ions and Bonding Particles	53%	Least Mastered

Interpretation: Mastered (80%-100%) Nearly Mastered (60%-79%) Least Mastered (40%-59%) Not Mastered (≤39%)

The results indicate varying levels of learner mastery across competencies related to chemical bonding, suggesting differences in conceptual difficulty and cognitive demand. Learners demonstrated the highest mastery in Types of Chemical Bonds and Compounds (60%), reflecting relatively stronger understanding of foundational concepts such as ionic, covalent, and metallic bonding. This finding aligns with previous studies showing that students tend to perform better on tasks requiring recognition and classification rather than application or analysis (Taber, 2013; Özmen, 2004). From the perspective of Bloom's Revised Taxonomy (Anderson & Krathwohl, 2001), this competency primarily targets lower-order cognitive skills such as remembering and understanding, which are generally more accessible to learners.

Moderate mastery levels were observed in Formation of Ions and Bonding Particles and Physical Properties of Ionic, Covalent, and Metallic Substances, both at 53%. These results suggest that learners possess partial understanding of how atoms gain or lose electrons and how bonding types relate to observable properties such as melting point, hardness, and electrical conductivity. However, the suboptimal mastery levels indicate difficulty in linking microscopic (particle-level) processes to macroscopic properties, a challenge consistently reported in chemistry education research (Johnstone, 1991; Gabel, 1999). According to Johnstone's Triangle, effective chemistry understanding requires coordination among macroscopic, submicroscopic, and symbolic representations. Learners' struggles in these areas suggest insufficient integration of these representational levels.

The lowest mastery level was found in Predicting Compound Type Based on Bonding Data (46%), indicating that learners experience the greatest difficulty with tasks requiring analysis, interpretation of data, and synthesis of multiple concepts. This competency involves higher order thinking skills such as analyzing and applying, which are cognitively demanding and require well-developed conceptual frameworks. Consistent with constructivist learning theory (Piaget, 1970; Driver et al., 1994), learners may struggle when prior knowledge is fragmented or when instruction does not explicitly support conceptual restructuring. Empirical studies have shown that students often rely on memorized rules rather than deep conceptual understanding when predicting compound behavior, leading to errors when faced with unfamiliar data or contexts (Bodner, 1986; Nahum et al., 2007).

3.5 Study Habits of the Learners in General Chemistry

This section explores the learners' study habits in learning General Chemistry. A total of thirty (30) Grade 11 learners from the Academic and Technical–Professional (TechPro) tracks participated in the study by responding to the open-ended study habits questionnaire and was thematically analyzed. The responses provide insight into the strategies and approaches employed by learners, particularly in mastering complex topics such as chemical bonding, and highlight patterns in study routines that may influence academic performance and conceptual understanding.

Table 8: Learners' Responses to the Study Habits Open-ended Questionnaire (Initial Codes to Themes)

Themes	Initial Codes	Description
Theme 1: Study Planning and Time Management	Fixed schedule, planned scheduling, daily routine, weekend studying, exam-focused planning, time adjustment, use of idle time, Pomodoro technique, checklist use, deadline tracking	This theme describes how learners organize, allocate, and manage their time for studying General Chemistry, including scheduling, prioritization, and adjustment based on academic demands.
Theme 2: Learning Strategies and Cognitive Techniques	Repetitive practice, chunking, self-testing, summarization, self-explanation, mastery-oriented practice, reinforcement, worked examples	This theme captures the cognitive and metacognitive strategies learners use to understand, practice, and master Chemistry concepts and problem-solving processes.
Theme 3: Conceptual Understanding and Knowledge Integration	Conceptual focus, concept-first approach, concept integration, foundational focus, knowledge linking, symbol interpretation, pattern recognition	This theme reflects learners' efforts to connect new Chemistry concepts with prior knowledge and to understand underlying principles rather than relying solely on memorization.
Theme 4: Resource Utilization and Learning Supports	Multimedia learning, online resources, educational apps, reference tool use, guided materials, personal glossary, visual aids	This theme represents the use of instructional resources, tools, and materials, both digital and teacher-provided, that support comprehension and retention of Chemistry lessons.
Theme 5: Social and Independent Learning Preferences	Independent learning, collaborative learning, peer discussion, peer support, hybrid approach, self-paced learning, focus control	This theme explains learners' preferences for studying alone, with peers, or using a combination of both, and how these choices influence focus, understanding, and motivation.
Theme 6: Motivation, Challenges, and Coping Mechanisms	Motivation boost, perseverance, stress management, initial difficulty, learning gaps, cognitive overload, help-seeking, clarification seeking	This theme encompasses learners' affective experiences, perceived difficulties, and coping strategies when dealing with complex and cumulative Chemistry content.

In theme 1, learners reported employing fixed schedules, planned routines, deadline tracking, and time-management techniques, such as the Pomodoro method, to organize their study sessions. These practices indicate an awareness of the importance of structuring study time to meet the cognitive demands of General Chemistry. This observation aligns with self-regulated learning (SRL) theory, which identifies time management as a critical predictor of academic achievement (Zimmerman, 2002). Empirical evidence further corroborates this association, demonstrating that effective time management strategies positively influence performance in science-related courses (Broadbent & Poon, 2015). However, learners' references to time adjustment and exam-focused planning suggest a reactive rather than proactive regulation approach, potentially constraining deeper conceptual engagement.

In theme 2, participants frequently reported strategies such as repetitive practice, self-testing, summarization, worked examples, and mastery-oriented exercises. These behaviors reflect active engagement with learning materials rather than passive reading and support the development of conceptual understanding through retrieval practice and self-explanation (Dunlosky et al., 2013; Chi et al., 1994). Nevertheless, the emphasis on repetition and reinforcement may indicate reliance on procedural memorization, which prior studies have associated with difficulties in transferring chemical bonding knowledge to novel problem contexts (Vladusic et al., 2023).

In theme 3, learners described efforts to focus on core concepts, connect new knowledge to prior understanding, and interpret chemical symbols and patterns. This approach demonstrates an intention to move beyond rote memorization toward integrated conceptual frameworks. Despite these efforts, research indicates persistent challenges in aligning symbolic, particulate, and macroscopic representations in chemical bonding, which may explain the observed gaps in higher-order competencies such as predicting compound types (Üce & Ceyhan, 2019; Rohmah et al., 2024).

In theme 4, learners frequently mentioned using online resources, multimedia tools, educational apps, guided materials, and visual aids, reflecting substantial engagement with technology-enhanced learning environments. Such strategies align with research indicating that visual and multimedia representations can facilitate comprehension of abstract chemistry concepts (Mayer, 2020). Nonetheless, evidence cautions that unstructured or excessive reliance on online materials may result in fragmented knowledge construction rather than cohesive conceptual understanding (Kirschner et al., 2006).

In theme 5, preferences for independent study, peer discussion, or hybrid approaches were evident, suggesting variability in learners' regulation of attention, motivation, and comprehension. These findings are consistent with social constructivist perspectives emphasizing collaborative knowledge construction (Vygotsky, 1978). At the same time, the preference for self-paced learning reflects the role of autonomy in motivation, as described by self-determination theory (Deci & Ryan, 2000).

In theme 6, learners highlighted strategies for maintaining motivation, perseverance, stress management, cognitive load regulation, and help-seeking behaviors. This theme underscores the affective dimension of chemistry learning, particularly when grappling with abstract and cumulative topics such as chemical bonding. Research indicates that cognitive overload and anxiety can impede conceptual understanding, whereas adaptive SRL behaviors, including help-seeking and clarification strategies, support effective learning (Sweller et al., 2019; Zimmerman & Moylan, 2009).

CONCLUSION AND RECOMMENDATION

The study yielded several key insights regarding Grade 11 learners' mastery of chemical bonding and associated self-regulated learning behaviors:

1. The Chemical Bonding Assessment Tool developed for this study is valid, reliable, and standardized, capable of effectively measuring learners' conceptual mastery in General Chemistry.

2. Learners demonstrated insufficient mastery of chemical bonding concepts, with most failing to achieve the required proficiency, particularly in tasks demanding higher-order thinking and data interpretation.

3. While learners exhibited relatively stronger understanding of basic bonding classifications, they struggled with application-based and analytical competencies, such as predicting compound types from bonding-related data.

4. Despite evidence of positive study habits and SRL behaviors, strategies were often procedural and exam-focused, potentially limiting the development of deep conceptual understanding.

5. Mastery gaps are influenced not only by content complexity but also by learners' approaches to studying, integrating concepts, and engaging with abstract chemical representations.

Based on the findings of this study, the following recommendations are proposed to strengthen learners' mastery of chemical bonding in Senior High School:

1. Curriculum and Assessment Design: Curriculum developers and educational institutions may expand the coverage of chemical bonding by incorporating application-based, data-driven, and higher-order thinking tasks. The systematic integration of validated diagnostic and mastery-based assessment tools is recommended to identify misconceptions and pinpoint the competencies that learners have least mastered.

2. Instructional Strategies: Teachers are encouraged to implement instructional approaches that explicitly address common misconceptions in chemical bonding, particularly in areas such as electron transfer, bonding models, and structure–property relationships. The use of multiple representations—symbolic, particulate, and macroscopic—combined with scaffolded problem-solving exercises is strongly recommended to reinforce conceptual understanding and facilitate cognitive integration.

3. Learner Study Strategies: Students may be guided to adopt deeper, more meaningful learning strategies, including self-explanation, concept mapping, and reflective learning practices. Emphasis should be placed on understanding underlying chemical principles rather than relying solely on procedural memorization or repetitive practice.

4. Future Research: Longitudinal and intervention-based studies are encouraged to examine the progression of chemical bonding mastery across grade levels. Additionally, further validation of the developed assessment tool across diverse educational contexts is recommended to establish its broader applicability and generalizability.

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