ASIAN JOURNAL OF EDUCATIONAL SCIENCES
ISSN: 0866-7675
eISSN: 2815-567X
DONG THAP UNIVERSITY JOURNAL OF SCIENCE - DONG THAP UNIVERSITY
https://ajesdthu.vn

DOI: ***https://doi.org/10.52714/dthu.ajes.17.2014***

Assessing the Effectiveness of Diagnostic Testing and Formative Feedback to Address Learning Deficiencies in Inorganic Chemistry

Elmer A. Irene[1*] and Ruel H. Amascual[2]

[1]*College of Education, Samar State University, Philippines*

[2]*College of Industrial Technology, Samar State University, Philippines*

[*]*Corresponding author, Email: elmer.irene@ssu.edu.ph*

Article Info.

Received: January 26, 2026

Revised: June 3, 2026

Accepted: June 19, 2026

Keywords

conceptual change, diagnostic assessment, formative feedback, higher-order thinking skills, inorganic chemistry, pre-service science teachers.

Cite

A. Irene, E., & H. Amascual, R. (2026). Assessing the Effectiveness of Diagnostic Testing and Formative Feedback to Address Learning Deficiencies in Inorganic Chemistry. *Asian Journal of Educational Sciences*, *1*(2), 29-45. https://doi.org/10.52714/dthu.ajes.17.2014

Abstract

Learning deficiencies in inorganic chemistry remain a persistent challenge among pre-service science teachers, particularly in conceptually demanding topics that require both content mastery and higher-order thinking skills (HOTS). This study assessed the effectiveness of integrating diagnostic testing and formative feedback in addressing learning deficiencies among Bachelor of Secondary Education major in Science students enrolled in an introductory inorganic chemistry course. Guided by Cognitive Load Theory and Conceptual Change Theory, the study employed a one-group pretest-posttest action research design involving 66 students. A 35-item diagnostic pretest and an equivalent posttest were administered to measure students' learning gains. Over the intervention, weekly diagnostic quizzes were conducted to identify students' misconceptions and learning difficulties, and the results were used to provide formative feedback and targeted instructional support. Results revealed significant improvements across all inorganic chemistry topics following the intervention ($p < .001$). The largest gains were observed in Coordination Compounds (14.24% to 90.30%) and Acids, Bases and Salts (26.97% to 93.94%). Higher-order thinking skills also improved substantially, increasing from 5.15% to 64.85%, although they remained lower than content-focused areas. Overall, students demonstrated marked gains in conceptual understanding and academic performance. The findings suggest that integrating diagnostic assessment with formative feedback is an effective strategy for identifying misconceptions, reducing learning deficiencies, and improving learning outcomes in inorganic chemistry. The study highlights the value of diagnostic-feedback cycles as an evidence-based instructional approach for strengthening content mastery and supporting the development of higher-order thinking skills among pre-service science teachers.

1. INTRODUCTION

Inorganic chemistry is widely recognized as one of the most challenging domains in science education because it requires students to demonstrate both a strong foundation of conceptual knowledge and advanced problem-solving abilities. Many undergraduate students, particularly those preparing to become science teachers, encounter difficulties in understanding abstract concepts such as atomic structure, periodic trends, acids and bases, redox reactions, and coordination compounds. These learning difficulties are often attributed to pre-existing misconceptions and fragmented conceptual understanding, with chemical bonding consistently identified as a major source of misunderstanding among learners (Özmen, 2004). To address these challenges, diagnostic assessment has emerged as an effective approach for identifying misconceptions and gaps in students' prior knowledge. By providing detailed information about students' learning needs, diagnostic assessments enable instructors to design targeted instructional interventions that enhance learning effectiveness (Suparman et al., 2024).

Beyond identifying misconceptions, conceptual change approaches offer a valuable framework for facilitating the reconstruction of students' scientific understanding and promoting meaningful learning (Treagust & Duit, 2008). However, diagnosis alone is insufficient to support conceptual development. Equally important is the provision of formative feedback that helps students recognize and address their learning difficulties. When delivered in a timely, specific, and constructive manner, formative feedback has been shown to enhance student engagement, support self-regulated learning, and maximize the effectiveness of formative assessment practices (Black & Wiliam, 2009).

Recent research underscores that integrating diagnostic assessment with formative feedback can markedly improve science learning. Meta-analytic evidence in higher education indicates that such integration significantly enhances students' academic performance and motivation (Morris, 2021). In chemistry and related disciplines, the integration of formative assessment tools, especially within inquiry-based learning frameworks, has been shown to improve students' conceptual understanding, particularly when feedback is provided at critical junctures throughout the learning process (Koksalan & Ogan-Bekiroglu, 2024). Similarly, in physics education, the use of cognitive diagnostic instruments combined with personalized and iterative feedback has been found to help lower-performing students achieve greater gains in problem-solving performance than their peers receiving conventional instruction (Pals et al., 2023). Moreover, timely and specific feedback plays a crucial role in reducing cognitive load, thereby enhancing learning efficiency (Hattie & Timperley, 2007; Shute, 2008). According to Cognitive Load Theory, minimizing extraneous cognitive load and promoting meaningful cognitive processing directly supports learning and conceptual understanding (Sweller et al., 2019).

In the context of inorganic chemistry, these strategies are especially relevant. The subject's complexity can easily overwhelm students if instruction is not responsive to their levels of readiness. Research shows that using diagnostic tools to identify misconceptions and then applying tailored interventions can effectively support students' conceptual development in challenging topics such as redox reactions (Easa & Blonder, 2022). Likewise, formative feedback practices in laboratory and classroom settings play a crucial role in helping learners consolidate understanding while also providing opportunities for more advanced students to extend their knowledge (Seery, 2020).

Despite the growing body of research supporting the use of diagnostic assessment and formative feedback in science education, important gaps remain in the literature. Previous studies have demonstrated the value of diagnostic assessment in identifying students' misconceptions and learning difficulties (Özmen, 2004; Suparman et al., 2024), while formative feedback has been shown to enhance student engagement, self-regulation, and academic achievement (Black & Wiliam, 2009; Hattie & Timperley, 2007). Other investigations have explored inquiry-based and diagnostic approaches in specific disciplinary contexts, highlighting their potential to improve conceptual understanding and problem-solving skills (Koksalan & Ogan-Bekiroglu, 2024; Pals et al., 2023). However, less attention has been given to the systematic integration of diagnostic assessment and formative feedback as complementary instructional strategies for addressing learning deficiencies in inorganic chemistry. Given the abstract and conceptually demanding nature of the subject, there remains a need to examine how the combined use of these approaches can support students' conceptual understanding and higher-order thinking skills. Addressing this gap may provide valuable insights into the design of evidence-based interventions for improving learning outcomes among pre-service science teachers.

Building on this evidence, the present study investigates the effectiveness of combining diagnostic testing and formative feedback in addressing learning deficiencies among Bachelor of Secondary Education major in Science students enrolled in an inorganic chemistry course. Also, the study examines how diagnostic assessment can be used to identify learning gaps and how targeted formative feedback can support improvements in both content mastery and higher-order thinking skills.

Specifically, the study sought to:

1. Identify students' learning deficiencies across selected topics in inorganic chemistry through diagnostic assessment;

2. Determine the effectiveness of diagnostic testing and formative feedback in improving students' content knowledge; and

3. Examine the extent to which the intervention enhances students' higher-order thinking skills (HOTS).

Accordingly, the following research questions guided the study:

1. What learning deficiencies do students exhibit in selected inorganic chemistry topics?

2. To what extent does diagnostic testing and formative feedback improve students' content knowledge?

3. To what extent does the intervention improve students' higher-order thinking skills?

4. Are there significant differences in learning gains across the different inorganic chemistry topics?

2. THEORETICAL FRAMEWORK AND CONCEPTUAL FOUNDATION

Diagnostic assessment is designed to identify students' prior knowledge, misconceptions, and learning difficulties before or during instruction. In science education, diagnostic testing serves as an important mechanism for uncovering gaps in conceptual understanding that may hinder subsequent learning (Suparman et al., 2024). By providing evidence of students' strengths and weaknesses, diagnostic assessment enables instructors to make informed instructional decisions and design targeted interventions that address specific learning needs. In chemistry education, diagnostic tools have been widely used to identify misconceptions related to chemical bonding, redox reactions, and other abstract concepts that frequently challenge learners (Easa & Blonder, 2022; Özmen, 2004).

While diagnostic assessment identifies learning deficiencies, feedback serves as the mechanism through which those deficiencies can be addressed. According to Hattie and Timperley (2007), effective feedback helps learners understand where they are in relation to learning goals, what progress they have made, and what actions are needed to improve performance. Similarly, Black and Wiliam (2009) emphasized that formative feedback is most effective when it is timely, specific, and directly linked to learning objectives. Formative feedback encourages self-regulated learning by helping students monitor their progress, identify misconceptions, and actively engage in improvement strategies (Nicol & Macfarlane-Dick, 2006). Consequently, integrating feedback into instructional practice can enhance both conceptual understanding and academic achievement.

The present study is further informed by Cognitive Load Theory, which posits that learning is optimized when instructional strategies minimize unnecessary cognitive demands and enable learners to allocate their mental resources to meaningful knowledge construction (Sweller et al., 2019). In chemistry education, students are often required to process abstract concepts, symbolic representations, and complex relationships simultaneously, placing substantial demands on working memory and potentially impeding learning. In the present study, diagnostic assessment and formative feedback function as complementary instructional strategies for managing cognitive load by detecting conceptual difficulties at an early stage and providing targeted support to address them. By concentrating instructional assistance on identified areas of difficulty rather than exposing students to excessive or irrelevant information, the intervention helps reduce extraneous cognitive load, focus attention on essential concepts, and promote deeper cognitive processing. Consequently, students are better positioned to develop accurate scientific understanding, enhance problem-solving performance, and strengthen higher-order thinking skills in inorganic chemistry.

Beyond the management of cognitive load, meaningful learning in chemistry requires students to revise or replace existing conceptions that are inconsistent with scientific explanations. This process is explained by Conceptual Change Theory, which suggests that learners reconstruct their understanding by replacing misconceptions with scientifically accepted concepts (Treagust & Duit, 2008). Chemistry learning frequently requires students to reorganize deeply rooted but scientifically inaccurate beliefs about chemical phenomena. Conceptual change occurs when learners become aware of limitations or inconsistencies in their existing understanding and are provided with opportunities to develop more coherent and scientifically valid explanations. Diagnostic assessment plays a critical role in identifying these alternative conceptions, while formative feedback facilitates the refinement of students' mental models through continuous reflection, clarification, and corrective guidance. Together, these complementary processes support meaningful learning and promote conceptual development.

As illustrated in Figure 1, the conceptual framework of this study posits that diagnostic assessment serves as the initial mechanism for identifying students' learning difficulties and alternative conceptions in inorganic chemistry. The information generated through diagnostic assessment provides the basis for targeted formative feedback, which supports students in addressing conceptual inaccuracies, deepening their understanding of key concepts, and enhancing their problem-solving abilities. Grounded in Cognitive Load Theory and Conceptual Change Theory, the framework assumes that timely, specific, and targeted feedback helps reduce extraneous cognitive load while facilitating the restructuring of students' existing knowledge structures toward scientifically accepted understandings. Through this process, students are expected to achieve greater content mastery, develop higher-order thinking skills, and demonstrate improved academic achievement in inorganic chemistry.

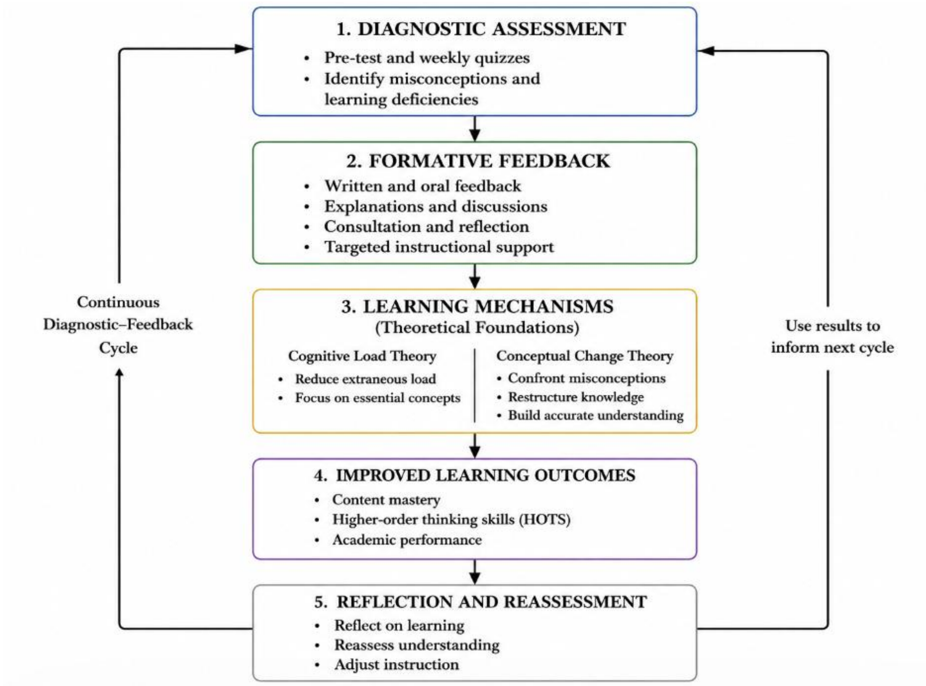

Figure 1. Conceptual Framework Linking Diagnostic Assessment, Formative Feedback, and Learning Outcomes in Inorganic Chemistry

3. METHODS

Research Design

This study adopted an Action Research approach, specifically a single-group pre-test–post-test design, to examine the impact of diagnostic assessment and formative feedback on students' learning difficulties in inorganic chemistry. The action research approach provided an opportunity for the researchers to systematically investigate and improve instructional practice while addressing students' identified learning needs. By focusing on a single group of students, the study enabled the monitoring of changes in learning outcomes following the intervention within an authentic classroom setting.

A single-group pre-test–post-test design was selected for this study due to both contextual and practical considerations. As Creswell and Creswell (2018) noted, research design should be responsive to the realities of the instructional context while ensuring equitable access to potential educational benefits. Because the course was delivered to intact class sections, establishing a separate control group would have required withholding diagnostic assessment and formative feedback from some students, thereby raising concerns regarding instructional equity and fairness. Furthermore, the primary purpose of this study was not to establish broadly generalizable causal relationships but rather to improve classroom practice through a cyclical process of planning, action, observation, and reflection. In this context, the single-group pre-test–post-test design was appropriate because it enabled the researchers to evaluate changes in student performance within the same cohort over time (Fraenkel et al., 2019).

Participants

The participants were undergraduate students enrolled in an introductory inorganic chemistry course at a state university in Samar, Philippines. The course was offered in two class sections, with an initial enrollment of 73 students. Following the exclusion of seven students due to incomplete data and irregular attendance during the intervention period, the final sample comprised 66 participants.

Although the participants were enrolled in two separate class sections, both sections received identical instructional content, diagnostic assessments, formative feedback interventions, learning activities, and assessment procedures throughout the study. Consequently, the two sections were combined and treated as a single cohort for analytical purposes. This approach was considered appropriate because the intervention was implemented consistently across both sections, and the primary objective of the study was to evaluate the overall effectiveness of diagnostic assessment and formative feedback in addressing students' learning difficulties in inorganic chemistry rather than to compare outcomes between sections.

To enhance the internal validity of the study, the same instructor implemented the intervention throughout the research period, ensuring consistency in instructional delivery, assessment procedures, and feedback practices. In addition, weekly diagnostic assessments and formative feedback sessions were systematically administered to monitor students' learning progress and provide targeted instructional support. Although the absence of a control group limits the ability to establish causal relationships, the repeated cycle of assessment, feedback, and reassessment provided evidence of changes in student performance over time within the same cohort.

Instrumentation

The primary instruments used in this study were a 35-item diagnostic pretest and a parallel 35-item posttest designed to assess students' conceptual understanding and higher-order thinking skills (HOTS) in selected inorganic chemistry topics. Both instruments consisted of multiple-choice questions with four response options and were constructed to measure students' knowledge across key chemistry concepts commonly encountered in the senior high school and introductory college chemistry curriculum.

The assessment covered seven major content areas: Periodic Table, Atomic Structure, Chemical Bonding, Acids, Bases and Salts, Redox Reactions, Coordination Compounds, and HOTS. Each content area was represented by five items, resulting in a total of 35 questions. The HOTS items were specifically designed to assess students' abilities to analyze, evaluate, and apply chemical concepts in solving complex problems, consistent with the higher cognitive levels of Bloom's revised taxonomy (Anderson & Krathwohl, 2001).

To establish content validity, the test blueprint was developed based on the chemistry competencies prescribed in the Grade 11 and Grade 12 science curriculum and aligned with the intended learning outcomes of the course. The distribution of items across topics ensured adequate representation of the major concepts and skills covered during instruction. The pretest and posttest were designed as parallel forms, sharing the same content coverage, cognitive demands, and item distribution while differing in item sequencing and presentation to minimize testing effects and ensure consistency in measuring learning gains.

Reliability analysis was conducted using Cronbach's alpha. The pretest yielded a Cronbach's alpha coefficient of 0.77, indicating acceptable internal consistency, while the posttest produced a coefficient of 0.90, indicating excellent internal consistency (Tavakol & Dennick, 2011). These values suggest that the instruments provided reliable measures of students' performance across the assessed content areas. The topics, competencies, and distribution of test items are presented in Table 1.

Table 1. List of Topics, Competencies and Number of Items

Topics	Competencies Tested	Number of Items
1. Periodic Table	Classify elements based on groups and periods; predict element properties using trends	5
2. Atomic Structure	Describe subatomic particles; apply quantum numbers; write electron configurations	5
3. Chemical Bonding	Distinguish between ionic, covalent, and metallic bonds; predict molecular shape	5
4. Acids, Bases and Salts	Identify properties of acids/bases; use pH scale; explain neutralization reactions	5
5. Redox Reactions	Determine oxidation states; identify oxidizing/reducing agents; balance redox equations	5
6. Coordination Compounds	Name coordination compounds; determine oxidation numbers; describe ligands and geometry	5
7. HOTS Level Questions	Analyze, synthesize, and evaluate complex chemical problems across multiple topics	5
Total		**35**

Data Collection

Pre-test Phase. The study commenced with a diagnostic pre-test designed to assess students' prior knowledge and understanding of selected inorganic chemistry topics. The results were used to identify areas of learning difficulty and conceptual gaps, thereby establishing a baseline for subsequent instructional interventions.

Preparatory and Monitoring Phase. Findings from the pre-test informed the design of targeted instructional interventions aimed at addressing identified learning needs. Throughout the intervention period, weekly diagnostic quizzes were administered to monitor students' progress, detect emerging misconceptions, and guide ongoing instructional adjustments.

Formative Feedback Phase. Following each diagnostic assessment, students received formative feedback through multiple channels, including written comments, oral explanations, classroom discussions, and individual consultations when necessary. The feedback focused on addressing conceptual misunderstandings, explaining common errors, reinforcing accurate reasoning, and providing specific guidance for improvement in areas where students experienced difficulty.

Post-test Phase. At the conclusion of the intervention period, students completed a post-test that paralleled the structure and content coverage of the pre-test. The post-test measured students' understanding of the same core concepts and was used to evaluate changes in knowledge acquisition, conceptual understanding, and problem-solving performance following the intervention.

Other Performance and Behavioral Indicators

Feedback and Reflection. As part of the action research process, students' perceptions of the intervention were gathered through open-ended survey questionnaires and interviews. These data provided insights into the perceived effectiveness of diagnostic testing and formative feedback and helped explain observed learning outcomes.

Classroom Observations. Classroom observations were conducted throughout the intervention period to document students' engagement, participation, and learning behaviors. These qualitative data complemented the quantitative findings and provided a more comprehensive understanding of how students interacted with the instructional strategies and course content.

Data Analysis

The pretest and posttest data were initially encoded and processed using Microsoft Excel and subsequently analyzed using JASP (version 0.95). Descriptive statistics, including raw scores, percentages, means, and standard deviations, were computed to summarize students' performance across the assessed inorganic chemistry topics. Students' raw scores were converted into percentages and interpreted using the following performance scale: 0-25% (Needs Improvement), 26-50% (Good), 51-75% (Very Good), and 76-100% (Excellent).

To determine whether the intervention resulted in significant improvements in student learning, paired-sample t-tests were conducted to compare pretest and posttest scores for each topic. This analysis was appropriate because the same group of students was assessed before and after the intervention. Reliability of the assessment instruments was evaluated using Cronbach's alpha coefficients to determine their internal consistency.

In terms of differences in performance across the seven inorganic chemistry topics, a one-way repeated-measures analysis of variance (ANOVA) was performed. This analysis enabled comparison of students' scores across multiple content areas while accounting for repeated measurements from the same participants. When significant differences were detected, Holm-adjusted post hoc pairwise comparisons were conducted to identify the specific topics that differed significantly from one another while controlling for familywise error. Statistical significance was evaluated at the 0.05 level for all analyses.

Ethical Considerations

Given that this study involved human participants, ethical principles were strictly observed to ensure the protection of participants' rights, privacy, and well-being. The following ethical considerations guided the conduct of the research:

Informed Consent. Prior to participation, all students were provided with an informed consent form outlining the purpose of the study, research procedures, potential risks, and anticipated benefits. Participants were informed that their involvement was entirely voluntary and that they could withdraw from the study at any time without penalty.

Confidentiality and Anonymity. All data collected during the study were treated with strict confidentiality. Personal identifiers were removed from datasets, analyses, and research reports to protect participants' anonymity. Assessment results, feedback records, and any additional data were securely stored and were accessible only to the researchers.

Minimization of Risk. The intervention was designed to support learning and improve academic outcomes. No physical, psychological, or academic harm was anticipated as a result of participation. Nevertheless, participants were encouraged to communicate any concerns or discomfort that arose during the study, and appropriate support was made available when necessary.

Voluntary Participation. Participants were assured that their decision to participate or decline participation would have no effect on their course grades, academic standing, or evaluation. No adverse consequences were associated with non-participation or withdrawal from the study.

Debriefing. Upon completion of the study, participants were provided with information regarding the research process and overall findings. This debriefing process promoted transparency, enabled participants to understand the purpose and contribution of their involvement, and provided an opportunity to ask questions or raise concerns about the study.

4. RESULTS AND DISCUSSION

The diagnostic pretest administered at the beginning revealed substantial learning deficiencies across multiple inorganic chemistry topics. Students demonstrated limited conceptual understanding based on raw scores per topic, with the lowest percentages recorded in complex areas such as coordination compounds and HOTS. Even foundational topics such as atomic structure, chemical bonding, and redox reactions yielded scores below 30%, indicating a broad need for targeted instructional support. Performance in the topic on the Periodic Table reached 36.06%, which, based on the study's adjectival rating scale, was interpreted as "Good." These results confirmed the presence of significant knowledge gaps and provided the basis for designing formative interventions tailored to students' needs.

Table 2 summarizes the diagnostic pretest and posttest results, providing a baseline snapshot of students' prior understanding across seven major inorganic chemistry topics and their subsequent improvement after the intervention. Reliability analysis indicated a Cronbach's alpha of 0.77 for the pretest, reflecting acceptable internal consistency, and 0.90 for the posttest, reflecting excellent internal consistency (Tavakol & Dennick, 2011).

Table 2. Diagnostic (Pretest) and Posttest Results of the Participants

Topic	Pretest Result			Posttest Result		
	Raw Score	% Score	Interpretation	Raw Score	% Score	Interpretation
1. Periodic Table (PT)	119	36.06%	Good	265	80.3%	Excellent
2. Atomic Structure (AS)	94	28.48%	Good	292	88.5%	Excellent
3. Chemical Bonding (CB)	95	28.79%	Good	295	89.4%	Excellent
4. Acids, Bases and Salts (ABS)	89	26.97%	Good	310	93.9%	Excellent
5. Redox reactions (Redox)	98	29.69%	Good	299	90.6%	Excellent
6. Coordination Compounds (CC)	47	14.24%	Needs Improvement	298	90.3%	Excellent
7. HOTS level questions (HOTS)	17	5.15%	Needs Improvement	214	64.8%	Very Good

After the implementation of diagnostic assessment and formative feedback, students demonstrated substantial improvement across all inorganic chemistry topics. Most content areas achieved posttest scores above 85%, indicating not only improved academic performance but also stronger conceptual understanding of key chemistry concepts. These gains suggest that the intervention enabled the early identification of misconceptions and learning deficiencies, allowing instructional support to be tailored to students' specific needs. Weekly diagnostic assessments provided continuous information regarding areas of difficulty, while timely and targeted feedback helped students recognize errors, refine their understanding, and monitor their progress. Consistent with the work of Hattie and Timperley

(2007) and Black and Wiliam (2009), the feedback process functioned not only as an evaluative tool but also as a mechanism for guiding learning and promoting self-regulation. From the perspective of Cognitive Load Theory, the intervention may have reduced unnecessary cognitive demands by directing students' attention to critical concepts and misconceptions, thereby facilitating more efficient processing of information and deeper conceptual understanding (Sweller et al., 2019).

Performance was particularly strong in content-focused areas. Acids, Bases, and Salts achieved the highest posttest score at 93.9% (310 points), followed by Redox Reactions at 90.6% (299), Coordination Compounds at 90.3% (298), Chemical Bonding at 89.4% (295), and Atomic Structure at 88.5% (292). These findings indicate that students were able to effectively address misconceptions and develop mastery of core concepts when provided with targeted instructional support and continuous feedback. The most notable gains occurred in Coordination Compounds and Redox Reactions, which were among the weakest areas in the pretest. This pattern suggests that diagnostic assessment enabled the instructor to focus instructional efforts on topics where misconceptions were most prevalent, thereby facilitating conceptual change and improved understanding.

Although students also demonstrated substantial gains in HOTS, performance in this domain remained lower than in the content-focused topics, with a posttest score of 64.8% (214 points). This finding suggests that the development of higher-order cognitive processes requires more sustained instructional support than the acquisition of conceptual knowledge. Unlike content mastery, HOTS involves the analysis, evaluation, and application of knowledge in unfamiliar situations, requiring students to integrate multiple concepts and engage in more complex reasoning. From the perspective of Cognitive Load Theory, students may have first needed to strengthen foundational knowledge before effectively engaging in higher-order tasks (Sweller et al., 2019). Similarly, Conceptual Change Theory suggests that restructuring misconceptions and developing sophisticated reasoning skills require repeated opportunities for reflection, feedback, and conceptual reconstruction (Treagust & Duit, 2008). Consequently, while the intervention successfully improved HOTS performance, the findings indicate that additional problem-based and inquiry-oriented learning experiences may be necessary to further strengthen students' analytical and evaluative skills.

These findings are consistent with previous studies emphasizing the importance of diagnostic assessment and formative feedback in science education. For example, Sayre et al. (2025) reported substantial learning deficiencies among Grade 11 Filipino learners across several chemistry topics, highlighting the need for targeted instructional interventions. Likewise, Rokhim et al. (2024) found strong support among chemistry educators for the use of diagnostic assessments to identify misconceptions and guide instructional decision-making. Together, these studies reinforce the value of evidence-based instructional approaches in addressing learning gaps and improving student achievement in chemistry.

Table 3. Statistical Comparison of the Pre-test and Posttest Scores

Topic	Pretest Mean (%)	Posttest Mean (%)	Mean Difference (%)	t-value	df	Decision
PT	36.06	80.30	44.24	13.6283	65	Significant
AS	28.48	88.48	60.00	24.5618	65	Significant
CB	28.79	89.39	60.61	24.0799	65	Significant
ABS	26.97	93.94	66.97	31.9962	65	Significant
Redox	29.70	90.61	60.91	24.3942	65	Significant

Topic	Pretest Mean (%)	Posttest Mean (%)	Mean Difference (%)	t-value	df	Decision
CC	14.24	90.30	76.06	32.0404	65	Significant
HOTS	5.15	64.85	59.70	21.2070	65	Significant

Across all seven topics, posttest scores increased substantially, and the paired-sample t-tests confirmed that these gains were statistically significant. This pattern is consistent with formative assessment research, which suggests that learning improves when instructors continuously elicit evidence of student understanding, interpret that evidence, and adjust instruction accordingly (Kingston & Nash, 2011; Ruiz-Primo & Furtak, 2007). The significant improvements observed across all topics indicate that the diagnostic assessment and formative feedback cycle enabled the identification of learning deficiencies and provided opportunities for targeted instructional support. From the perspective of Conceptual Change Theory, these gains suggest that students were able to confront misconceptions and gradually replace them with scientifically acceptable explanations through continuous feedback and guided learning experiences (Treagust & Duit, 2008).

The particularly large gains observed in content-focused topics such as Coordination Compounds, Acids, Bases and Salts, Chemical Bonding, and Redox Reactions are consistent with chemistry education research emphasizing the importance of linking macroscopic, submicroscopic, and symbolic representations during instruction (Johnstone, 2000). By providing targeted feedback on areas of difficulty, the intervention may have helped students establish stronger connections among these representations, thereby facilitating conceptual understanding. Furthermore, from the perspective of Cognitive Load Theory, diagnostic assessment and feedback likely reduced extraneous cognitive load by directing students' attention to critical concepts and misconceptions rather than requiring them to process excessive or irrelevant information (Sweller et al., 2019).

Although HOTS scores improved significantly, they remained lower than those of the content-focused topics. This finding suggests that while diagnostic assessment and feedback were effective in strengthening conceptual understanding, the development of higher-order thinking skills requires additional opportunities for analysis, evaluation, and knowledge transfer. Such tasks involve greater cognitive demands because students must integrate multiple concepts and apply them in unfamiliar situations. Similarly, the comparatively smaller gains observed in the Periodic Table topic may reflect the persistent difficulties students experience in understanding periodic trends and the explanatory reasoning that underpins them (Chowdhury, 2022; Mokiwa, 2017). These findings highlight the need for continued use of multi-representational, inquiry-based, and problem-centered learning experiences to further strengthen students' higher-order thinking and reasoning skills in chemistry.

Table 4. ANOVA Results (Repeated-measures Across Topics)

Measure	Term	Value	Meaning
Pretest Topics	F value	60.30	Very high
Pretest Topics	F critical ($\alpha = .05$)	2.12	Threshold for significance
Pretest Topics	p-value	$< .001$	Extremely significant
Posttest Topics	F value	26.38	Very high
Posttest Topics	F critical ($\alpha = .05$)	2.12	Threshold for significance

Measure	Term	Value	Meaning
Posttest Topics	p-value	< .001	Extremely significant
Gains (Post − Pre)	F value	16.71	High
Gains (Post − Pre)	F critical (α = .05)	2.12	Threshold for significance
Gains (Post − Pre)	p-value	< .001	Extremely significant

Note. One-way repeated-measures ANOVA across 7 topics (within-subjects); df_topic = 6, df_error = 390 (n = 66). Topic scores are 0-5; results are invariant to linear scaling

The repeated-measures ANOVA revealed significant differences in student performance across the seven inorganic chemistry topics throughout the study. Prior to the intervention, performance varied considerably among topics, $F(6, 390) = 60.30$, $p < .001$, $\eta p^2 = .48$, indicating substantial differences in students' prior knowledge and the prevalence of topic-specific misconceptions. Following the implementation of diagnostic assessment and formative feedback, performance improved across all content areas. Although differences among topics remained statistically significant, $F(6, 390) = 26.38$, $p < .001$, $\eta p^2 = .29$, the reduction in effect size suggests that the intervention helped narrow performance disparities and promote more balanced learning outcomes across topics.

The significant variation in gain scores, $F(6, 390) = 16.71$, $p < .001$, $\eta p^2 = .20$, indicates that the effectiveness of the intervention differed across content areas. The largest gains were observed in Coordination Compounds and Acids, Bases, and Salts, which were among the topics with the lowest pretest performance. These findings suggest that diagnostic assessment successfully identified areas of conceptual difficulty, allowing targeted feedback and instructional adjustments to focus on students' most pressing learning needs. Consistent with Conceptual Change Theory, students appeared to benefit from opportunities to confront misconceptions and reconstruct their understanding through continuous feedback and guided learning experiences (Treagust & Duit, 2008).

Despite the overall improvement, differences among topics persisted in the posttest, indicating that some concepts remained inherently more challenging than others. In particular, Periodic Table concepts and HOTS continued to yield comparatively lower scores. Understanding periodic trends requires students to integrate multiple conceptual relationships and explanatory mechanisms, while HOTS tasks demand the analysis, evaluation, and application of knowledge in unfamiliar contexts. From the perspective of Cognitive Load Theory, these tasks impose greater cognitive demands because learners must simultaneously process and integrate multiple pieces of information (Sweller et al., 2019). Consequently, although diagnostic assessment and formative feedback effectively improved performance, more sustained exposure to inquiry-based, problem-centered, and multi-representational learning experiences may be necessary to further strengthen students' reasoning and higher-order thinking skills.

Taken together, the ANOVA findings reinforce the results of the paired-sample t-tests by demonstrating that the intervention contributed to substantial learning gains across all topics while reducing performance disparities among content areas. The results highlight the value of combining diagnostic assessment with formative feedback as a means of identifying learning deficiencies, guiding instructional decisions, and supporting meaningful conceptual development in inorganic chemistry.

Table 5. Post hoc Pairwise Comparisons (Within-subjects)

Contrast	Mean Diff (%-pts)	95% CI (low)	95% CI (high)	t(65)	p (Holm)	Sig (.05)
HOTS − ABS	-29.09	-34.82	-23.36	-10.1349	1.119e-13	True
HOTS − CC	-25.45	-30.81	-20.1	-9.4943	1.346e-12	True
ABS − PT	13.64	7.06	20.21	4.1407	1.528e-03	True
CC − PT	10.0	3.71	16.29	3.1734	3.223e-02	True
Redox − PT	10.3	3.78	16.83	3.1535	3.223e-02	True
HOTS − AS	-23.64	-29.08	-18.19	-8.6642	3.489e-11	True
HOTS − Redox	-25.76	-31.33	-20.18	-9.2296	3.717e-12	True
HOTS − CB	-24.55	-30.25	-18.84	-8.589	4.477e-11	True
HOTS − PT	-15.45	-22.5	-8.41	-4.3789	7.090e-04	True

Note. Paired comparisons between topics within subjects; two-tailed paired t-tests with Holm adjustment for familywise error. df = 65 (n = 66)

The Holm-adjusted post hoc comparisons provided a more detailed understanding of the differences among topics following the intervention. The results revealed that HOTS remained significantly lower than several content-focused areas, including Acids, Bases and Salts (ABS), Coordination Compounds (CC), Atomic Structure (AS), Chemical Bonding (CB), and Redox Reactions. The largest difference was observed between HOTS and ABS, with ABS outperforming HOTS by approximately 29 percentage points. Similarly, HOTS scores were significantly lower than those in Coordination Compounds, Redox Reactions, Atomic Structure, and Chemical Bonding. These findings indicate that although students demonstrated substantial gains in higher-order thinking skills, their performance in tasks requiring analysis, evaluation, and application of knowledge remained less developed than their mastery of content-specific concepts.

Significant differences were also observed between the Periodic Table (PT) and several content-focused topics. Acids, Bases and Salts, Coordination Compounds, and Redox Reactions all achieved significantly higher scores than the Periodic Table, suggesting that students continued to experience greater difficulty with concepts involving periodic trends and explanatory reasoning. Understanding periodic behavior requires learners to integrate multiple concepts, recognize patterns, and explain relationships among atomic properties, which may present greater conceptual challenges than topics that rely more heavily on procedural or conceptual recall.

From the perspective of Cognitive Load Theory, both HOTS and Periodic Table tasks likely imposed greater cognitive demands because students were required to process and integrate multiple pieces of information simultaneously (Sweller et al., 2019). Similarly, Conceptual Change Theory suggests that developing higher-order reasoning and overcoming deeply rooted misconceptions require extended opportunities for reflection, feedback, and conceptual restructuring (Treagust & Duit, 2008). The persistence of significant differences in these areas therefore highlights the need for instructional approaches that extend beyond content mastery and incorporate inquiry-based learning, problem-solving activities, and multi-representational tasks. Such strategies may further strengthen students' analytical reasoning, transfer of knowledge, and higher-order thinking skills in inorganic chemistry.

5. CONCLUSION, IMPLICATIONS, LIMITATIONS, AND FUTURE DIRECTIONS

The findings of this study indicate that the integration of diagnostic assessment and formative feedback constitutes an effective instructional approach for addressing students' learning difficulties in inorganic chemistry. Students entered the course with uneven and generally limited prior knowledge across major chemistry topics. Following the intervention, statistically significant gains were observed across all content areas, with particularly substantial improvements in Acids, Bases and Salts, Redox Reactions, Coordination Compounds, Chemical Bonding, and Atomic Structure. These findings suggest that systematically identifying conceptual difficulties through diagnostic assessment and responding to them with timely and targeted formative feedback can enhance students' conceptual understanding and academic achievement. From the perspective of Cognitive Load Theory, the intervention may have supported learning by directing students' attention toward critical concepts and reducing unnecessary cognitive demands. Likewise, the findings are consistent with Conceptual Change Theory, as the diagnostic-feedback cycle provided opportunities for students to recognize and revise inaccurate conceptions. Although HOTS and understanding of Periodic Table concepts also improved significantly, performance in these areas remained comparatively lower, suggesting that they require more sustained instructional support and opportunities for complex reasoning and knowledge application.

The findings have several implications for chemistry instruction and educational practice. *First,* diagnostic assessment should be incorporated into routine classroom practice to identify conceptual difficulties before they become significant barriers to learning. *Second,* formative feedback should be embedded throughout the instructional process to provide students with timely, specific, and actionable guidance. *Third,* chemistry educators should employ multi-representational instructional strategies, inquiry-based learning activities, and problem-centered tasks to strengthen students' understanding of abstract concepts and foster higher-order thinking skills. At the institutional level, teacher education programs may consider integrating diagnostic–feedback cycles into their instructional frameworks to promote evidence-based teaching practices and enhance learning outcomes in science education.

Several limitations should be acknowledged when interpreting the findings. The study employed a single-group pre-test–post-test design without a comparison group, limiting the extent to which observed improvements can be attributed solely to the intervention. In addition, the assessment instrument consisted of relatively short topic-specific subtests, which may not have fully captured the complexity of students' conceptual understanding and reasoning processes. Furthermore, the study was conducted within a single institutional context, which may restrict the transferability of the findings to other educational settings.

Future research should investigate the effectiveness of diagnostic assessment and formative feedback using quasi-experimental or experimental designs that incorporate comparison groups. Longitudinal studies are also needed to examine the extent to which learning gains are retained and transferred across contexts over time. Further investigations may employ detailed item-level and distractor analyses to better understand the persistence and resolution of specific misconceptions. In addition, future research could explore the integration of digital technologies and artificial intelligence-supported diagnostic systems to deliver real-time feedback and personalized learning support in chemistry education.

DECLARATIONS

Funding: This research received no external or institutional research funding. The study was conducted as a college-based research initiative using available institutional resources.

Institutional Review Board Statement: The study was conducted as a college-based research initiative at Samar State University, Philippines. The research was properly acknowledged and conducted with the knowledge and permission of the concerned academic unit. Formal ethical clearance was not obtained because, under the institutional policy applicable at the time of the study, ethical review was required for institutionally funded research, and this study did not receive institutional research funding. Nevertheless, the researchers observed appropriate ethical principles in the conduct of the study, including informed consent for the participants, voluntary participation, confidentiality, and responsible handling and reporting of the data.

Transparency: The authors confirm that the manuscript presents an accurate and transparent account of the research. All essential aspects of the study, including the research design, methodology, data collection, analysis, and findings, have been reported accurately and completely.

Competing Interests: The authors declare that they have no competing financial or personal interests that could have influenced the conduct, analysis, interpretation, or reporting of this research.

Authors' Contributions: Elmer A. Irene contributed to the conceptualization and design of the study, development of the methodology, data analysis and interpretation, and preparation and revision of the manuscript. Ruel H. Amascual contributed to data collection, implementation of the study, interpretation of findings, and critical review of the manuscript. Both authors reviewed and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Disclosure of AI Use: ChatGPT, developed by OpenAI, was used during the preparation and revision of this manuscript to assist with language editing, grammar checking, sentence refinement, organization, and improvement of clarity and readability. ChatGPT was not used to collect, generate, analyze, or interpret the research data, nor was it used to determine the study's findings or conclusions. The authors independently reviewed and verified all AI-assisted content and remain fully responsible for the accuracy, originality, integrity, and final content of the manuscript.

REFERENCES

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Longman.

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability, 21*(1), 5-31. https://doi.org/10.1007/s11092-008-9068-5

Chowdhury, P. (2022). Learners' misconceptions in periodic table: An analysis of cognitive skills development. *Universal Journal of Educational Research, 10*(1), 57-66. https://doi.org/10.13189/ujer.2022.100106

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

Easa, E., & Blonder, R. (2022). Development and validation of customized pedagogical kits for high-school chemistry teaching and learning: The redox reaction example. *Chemistry Teacher International, 4*(1), 89-96. https://doi.org/10.1515/cti-2021-0022

Felder, R. M., & Brent, R. (2005). Understanding student differences. *Journal of Engineering Education, 94*(1), 57-72. https://doi.org/10.1002/j.2168-9830.2005.tb00829.x

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2019). *How to design and evaluate research in education* (10th ed.). McGraw-Hill Education.

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research, 77*(1), 81-112. https://doi.org/10.3102/003465430298487

Johnstone, A. H. (2000). Teaching of chemistry—Logical or psychological? *Chemistry Education Research and Practice, 1*(1), 9-15. https://doi.org/10.1039/A9RP90001B

Kingston, N., & Nash, B. (2011). Formative assessment: A meta-analysis and a call for research. *Educational Measurement: Issues and Practice, 30*(4), 28-37. https://doi.org/10.1111/j.1745-3992.2011.00220.x

Koksalan, S., & Ogan-Bekiroglu, F. (2024). Examination of effects of embedding formative assessment in inquiry-based teaching on conceptual learning. *Science Insights Education Frontiers, 20*(2), 3223-3246. https://doi.org/10.15354/sief.24.or512

Mokiwa, H. O. (2017). Reflections on teaching periodic table concepts: A case study of selected schools in South Africa. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(6), 1563-1573. https://doi.org/10.12973/eurasia.2017.00685a

Morris, R., Perry, T., & Wardle, L. (2021). Formative assessment and feedback for learning in higher education: A systematic review. *Review of Education, 9*(3), Article e3292. https://doi.org/10.1002/rev3.3292

Nicol, D. J., & Macfarlane-Dick, D. (2006). Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education, 31*(2), 199-218. https://doi.org/10.1080/03075070600572090

Özmen, H. (2004). Some student misconceptions in chemistry: A literature review of chemical bonding. *Journal of Science Education and Technology, 13*(2), 147-159. https://doi.org/10.1023/B:JOST.0000031255.92943.6d

Pals, F. F. B., Tolboom, J. L. J., & Suhre, C. J. M. (2023). Development of a formative assessment instrument to determine students' need for corrective actions in physics: Identifying students' functional level of understanding. *Thinking Skills and Creativity, 50*, Article 101387. https://doi.org/10.1016/j.tsc.2023.101387

Rokhim, D. A., Widarti, H. R., & Sutrisno. (2024). Profile of needs analysis of five-tier diagnostic instrument development for high school chemistry courses. *Pegem Journal of Education and Instruction*, *14*(2), [Article]. https://doi.org/10.47750/pegegog.14.02.17

Ruiz-Primo, M. A., & Furtak, E. M. (2007). Exploring teachers' informal formative assessment practices and students' understanding in science. *Journal of Research in Science Teaching, 44*(1), 57-84. https://doi.org/10.1002/tea.20163

Sayre, J., Nabua, E., Salic-Hairulla, M., Alcopra, A., & Fernandez, M. J. (2025). Assessing general chemistry learning gaps: A needs assessment of competency mastery among

Grade 11 learners. *International Journal of Research and Innovation in Social Science, 9*(4), 6518-6524. https://doi.org/10.47772/IJRISS.2025.90400472

Seery, M. K. (2020). Establishing the laboratory as the place to learn how to do chemistry. *Journal of Chemical Education, 97*(6), 1511-1514. https://doi.org/10.1021/acs.jchemed.9b00764

Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research, 78*(1), 153-189. https://doi.org/10.3102/0034654307313795

Suparman, A. R., Rohaeti, E., & Wening, S. (2024). Development of computer-based chemical five-tier diagnostic test instruments: A generalized partial credit model. *Journal on Efficiency and Responsibility in Education and Science*, *17*(1), 92-106. https://doi.org/10.7160/eriesj.2024.170108

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive load theory: Recent theoretical advances. *Educational Psychology Review, 31*(4), 261-283. https://doi.org/10.1007/s10648-019-09465-5

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education, 2,* 53-55. https://doi.org/10.5116/ijme.4dfb.8dfd

Treagust, D. F., & Duit, R. (2008). Conceptual change: A discussion of theoretical, methodological and practical challenges for science education. *Cultural Studies of Science Education, 3*(2), 297-328. https://doi.org/10.1007/s11422-008-9090-4