

Tracking the Sources of Misconceptions in Inorganic Chemistry: Textbooks, Teachers, or Curriculum

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Abstract

This study investigates the root causes of persistent student misconceptions in inorganic chemistry at the undergraduate level. Despite instructional efforts, misconceptions remain widespread, affecting student performance and conceptual understanding. A comparative analysis of chemistry textbooks, structured interviews with teachers, and curriculum mapping were conducted to identify whether textbooks, teaching practices, or curriculum design contribute most significantly to these misconceptions. Findings suggest that curriculum gaps and inconsistent textbook representations are key contributors, while teacher interpretation plays a mediating role. Based on these results, recommendations for teaching practice and curriculum reform are proposed.

Keywords: Inorganic chemistry, misconceptions, curriculum mapping, textbook analysis, teacher interviews

1. Introduction

Inorganic chemistry forms a foundational component of chemical education, playing a critical role in the development of conceptual understanding necessary for advanced study in chemistry, materials science, pharmacy, and engineering. Despite its importance, students at secondary and tertiary levels consistently

demonstrate persistent misconceptions in key inorganic chemistry concepts such as oxidation states, periodic trends, chemical bonding, coordination compounds, and acid–base behavior. These misconceptions not only impair academic performance but also hinder the development of scientific reasoning and problem-solving skills.

Misconceptions are defined as deeply rooted alternative conceptions that deviate from scientifically accepted explanations and are often resistant to traditional instructional methods. In chemistry education research, misconceptions are widely recognized as robust cognitive structures that persist even after formal instruction. In inorganic chemistry, these misconceptions are particularly problematic due to the abstract nature of concepts, symbolic representations, and the heavy reliance on models and theoretical constructs rather than observable phenomena.

Previous studies have extensively documented *what* misconceptions students hold; however, significantly less attention has been paid to *why* these misconceptions persist across educational levels. Students often progress from secondary education to undergraduate studies carrying forward flawed conceptual frameworks, suggesting that the issue is systemic rather than individual. Three dominant sources are frequently implicated: instructional textbooks, teacher-mediated explanations, and curriculum design. Yet, these factors are rarely examined together within a single analytical framework.

Textbooks remain the primary learning resource in chemistry education, particularly in contexts where teacher-centered pedagogy dominates. While textbooks are expected to present accurate, coherent, and conceptually sound explanations, research indicates that many chemistry textbooks oversimplify complex topics, present inconsistent definitions, or fail to adequately link macroscopic, sub-microscopic, and symbolic representations. Such shortcomings may unintentionally reinforce incorrect mental models in learners.

Teachers play a mediating role between curriculum and learner understanding. Their subject matter knowledge, pedagogical content knowledge, and instructional strategies can either correct or perpetuate misconceptions. In many cases, teachers themselves may hold incomplete or alternative conceptions, particularly when professional development opportunities are limited. Moreover, pressure to complete extensive syllabi often restricts opportunities for diagnostic assessment and conceptual remediation.

Curriculum structure is another critical yet underexplored factor. Poor sequencing of topics, inadequate emphasis on prerequisite knowledge, and misalignment between

learning objectives and assessment practices can create cognitive overload and conceptual fragmentation. When foundational ideas such as atomic structure and bonding are insufficiently reinforced before introducing advanced inorganic topics, misconceptions are likely to emerge and persist.

Given these interrelated influences, there is a pressing need for a comprehensive investigation that traces the origins of inorganic chemistry misconceptions across textbooks, teachers, and curriculum design. Understanding the relative contribution of each factor is essential for developing targeted interventions that move beyond surface-level instructional fixes toward systemic educational reform.

1.1 Objectives of the Study

The present study aims to conduct a root cause analysis of persistent student misconceptions in inorganic chemistry through a comparative examination of textbooks, teacher perspectives, and curriculum frameworks. The specific objectives are:

i. To identify commonly held misconceptions in inorganic chemistry among undergraduate students.

ii. To critically analyze the presentation of inorganic chemistry concepts in widely used textbooks.

iii. To explore teachers' perceptions regarding the origins and persistence of student misconceptions.

iv. To examine curriculum structure and sequencing for potential conceptual gaps.

v. To determine the relative contribution of textbooks, teachers, and curriculum to student misconceptions.

vi. To propose evidence-based recommendations for teachers, curriculum designers, and policymakers.

1.2 Research Gap

Although chemistry education research has made significant progress in cataloging student misconceptions, existing studies are largely fragmented and focus primarily on learner cognition. There is a noticeable lack of integrative studies that simultaneously examine instructional materials, teaching practices, and curriculum design as interconnected sources of misconceptions. Furthermore, limited empirical research has employed curriculum mapping alongside textbook analysis and teacher interviews to trace conceptual inconsistencies across educational levels. This study addresses this

gap by adopting a holistic, systems-based approach to understanding misconception formation in inorganic chemistry.

1.3 Hypotheses

Based on existing literature and preliminary observations, the study is guided by the following hypotheses:

- **H1:** Inconsistencies and oversimplifications in inorganic chemistry textbooks significantly contribute to student misconceptions.
- **H2:** Teachers' instructional interpretations and pedagogical approaches influence the persistence of misconceptions.
- **H3:** Structural gaps and improper sequencing within the curriculum are a primary source of enduring conceptual misunderstandings.
- **H4:** Curriculum design exerts a stronger influence on misconceptions than individual teaching practices or textbook content alone.

2. Literature Review

2.1 Conceptualizing Misconceptions in Chemistry Education

Misconceptions in chemistry education have long been recognized as stable cognitive structures that differ from scientifically accepted explanations and persist despite

formal instruction. Early constructivist theories emphasize that learners actively construct knowledge based on prior experiences, which may not align with scientific models. In chemistry, this challenge is intensified by the abstract nature of concepts, symbolic representations, and the necessity to integrate macroscopic observations with sub-microscopic and symbolic levels of understanding.

Inorganic chemistry, in particular, presents a fertile ground for misconception formation due to its reliance on theoretical constructs such as atomic orbitals, oxidation states, coordination geometry, and periodic trends. Studies have shown that students often rely on memorization rather than conceptual understanding, leading to fragmented knowledge structures that fail to support higher-order reasoning. Misconceptions in inorganic chemistry are not transient errors but deeply embedded alternative frameworks that frequently persist from secondary school into undergraduate and postgraduate education.

2.2 Student-Centered Studies on Inorganic Chemistry Misconceptions

A substantial body of research has focused on identifying and categorizing misconceptions held by students in inorganic chemistry.

Commonly reported misconceptions include misunderstanding oxidation numbers as physical charges, confusion between ionic and covalent bonding, incorrect interpretation of periodic trends, and flawed reasoning about coordination compounds and ligand behavior. Comparative studies across educational levels reveal that many misconceptions remain unchanged despite progression through the curriculum. This persistence suggests that instructional interventions often fail to address the root causes of misunderstanding. Research comparing secondary and undergraduate learners indicates that higher-level instruction frequently builds upon assumed prior knowledge that may itself be conceptually flawed, thereby reinforcing incorrect mental models rather than correcting them.

Your study “Unveiling Misconceptions in Chemical Bonding: A Comparative Study Across Secondary and Undergraduate Levels” (Shodh Sari, 2025) contributes significantly to this body of work by empirically demonstrating the continuity of bonding-related misconceptions across educational stages. The findings highlight that misconceptions are not merely developmental gaps but systemic instructional failures that transcend academic levels.

2.3 Role of Analogies, Metaphors, and Language in Misconception Formation

Analogies and metaphors are widely employed in chemistry teaching to simplify abstract concepts. While they can facilitate initial understanding, research increasingly indicates that poorly designed or overextended analogies may propagate misconceptions. Learners may focus on surface similarities rather than structural correspondences, leading to distorted conceptual interpretations.

Your work “Impact of Analogies and Metaphors in Propagating Misconceptions in Chemical Education” (Shodh Sari, 2025) provides empirical evidence that commonly used instructional analogies—such as planetary models for atomic structure or rigid ball-and-stick representations for bonding—often introduce unintended misconceptions. The study underscores that metaphoric language, when not explicitly bounded, can solidify incorrect assumptions that persist into advanced learning stages.

These findings align with broader literature suggesting that instructional language and representational choices play a critical role in shaping learner cognition. In inorganic chemistry, where abstract theoretical models dominate, imprecise metaphors may

inadvertently replace scientific reasoning with intuitive but incorrect explanations.

2.4 Visual Representations and Molecular Modeling

Visual tools such as molecular models, diagrams, and simulations are central to inorganic chemistry education. While these tools are intended to bridge the gap between abstract theory and conceptual understanding, their effectiveness depends heavily on instructional design and learner interpretation. Research indicates that students often interpret visual representations literally, mistaking models for reality rather than symbolic constructs. Static diagrams may oversimplify dynamic processes, while three-dimensional molecular models may reinforce incorrect assumptions about rigidity, scale, or spatial relationships.

Your study “Visual vs Conceptual Understanding: Addressing Misconceptions Through Molecular Modeling in Inorganic Chemistry” (Edumania, 2025) critically examines this issue by contrasting visual familiarity with genuine conceptual comprehension. The findings demonstrate that while molecular modeling enhances engagement, it does not automatically correct misconceptions unless paired with explicit

conceptual scaffolding. This work highlights the distinction between visual recognition and deep understanding, reinforcing the need for pedagogical strategies that go beyond representational exposure.

2.5 Textbooks as a Source of Conceptual Inconsistencies

Textbooks remain the dominant instructional resource in chemistry education, particularly in examination-oriented systems. However, multiple studies have documented conceptual inaccuracies, inconsistent definitions, and oversimplified explanations in inorganic chemistry textbooks. These issues are especially pronounced in topics such as oxidation states, periodicity, and coordination chemistry, where conceptual nuance is essential.

Textbook analyses reveal frequent misalignment between textual explanations, diagrams, and end-of-chapter problems. In some cases, symbolic equations are introduced without adequate conceptual grounding, encouraging algorithmic problem-solving rather than understanding. Such presentation styles may inadvertently legitimize misconceptions by presenting them in authoritative formats.

Despite their influence, textbooks are often excluded from misconception research, which tends to focus primarily on learner cognition. This omission limits the ability to trace misconceptions to their instructional origins.

2.6 Teachers' Pedagogical Content Knowledge and Instructional Practices

Teachers serve as critical mediators between curriculum content and student understanding. Research on pedagogical content knowledge (PCK) indicates that effective misconception remediation requires not only subject expertise but also an awareness of common student difficulties and appropriate diagnostic strategies.

However, studies suggest that teachers themselves may hold partial or alternative conceptions, particularly in abstract areas of inorganic chemistry. Time constraints, syllabus pressure, and assessment-driven instruction further limit opportunities for conceptual clarification. As a result, teachers may unintentionally reinforce textbook-derived misconceptions or rely on heuristic explanations that lack conceptual rigor.

Interview-based studies emphasize that many educators recognize student difficulties but attribute them primarily to learner ability

rather than instructional design, thereby overlooking systemic factors.

2.7 Curriculum Design and Structural Causes of Misconceptions

Curriculum structure plays a foundational role in shaping conceptual development. Poor sequencing of topics, inadequate emphasis on prerequisite concepts, and misalignment between learning objectives and assessments have been identified as major contributors to persistent misconceptions.

In inorganic chemistry, advanced topics are often introduced before students have developed a robust understanding of atomic structure, bonding, and periodic behavior. Curriculum mapping studies reveal conceptual gaps and redundancy across educational levels, suggesting a lack of vertical coherence.

Despite its importance, curriculum analysis remains underrepresented in misconception research. Few studies systematically examine how curricular frameworks contribute to the formation and persistence of alternative conceptions.

2.8 Synthesis and Rationale for the Present Study

The reviewed literature demonstrates that misconceptions in inorganic chemistry are multifactorial and deeply embedded within

educational systems. While student-centered studies dominate the field, emerging evidence—including your prior research—indicates that textbooks, instructional language, visual representations, teaching practices, and curriculum design collectively shape learner understanding.

However, there remains a lack of integrative research that simultaneously examines these factors within a unified analytical framework. This study addresses this gap by conducting a comparative analysis of textbooks, teacher perspectives, and curriculum structures to trace the root causes of persistent misconceptions in inorganic chemistry.

3. Methodology

The present study adopted a mixed-method, descriptive–analytical research approach to investigate the root causes of persistent misconceptions in inorganic chemistry, with specific emphasis on textbooks, teachers, and curriculum design as potential sources. A triangulation strategy was employed to enhance the validity and reliability of findings by integrating qualitative and quantitative data derived from textbook analysis, teacher interviews, and curriculum mapping. This methodological design enabled a comprehensive examination of instructional,

pedagogical, and structural factors influencing student understanding.

The study was conducted across undergraduate chemistry programs affiliated with universities and colleges following nationally prescribed curricula. Purposive sampling was used to select data sources that are representative and widely influential in chemistry education. The sample included commonly prescribed inorganic chemistry textbooks, in-service chemistry teachers with a minimum of five years of teaching experience, and officially approved curriculum documents at the secondary and undergraduate levels.

Textbook analysis constituted the first component of the methodology. Six widely used inorganic chemistry textbooks—three at the senior secondary level and three at the undergraduate level—were selected based on frequency of adoption, alignment with national syllabi, and recommendations by academic institutions. A content analysis framework was developed to evaluate conceptual accuracy, clarity of explanations, use of analogies and metaphors, representational consistency, and alignment between textual descriptions and visual elements. Particular attention was given to core inorganic chemistry topics known for high misconception prevalence, including

oxidation states, periodic trends, chemical bonding, coordination compounds, and acid–base theories. Each textbook was systematically reviewed, and instances of oversimplification, ambiguous language, inconsistent definitions, and misleading representations were coded and documented. Inter-coder reliability was ensured by involving two subject experts who independently reviewed a subset of the content, achieving a high level of agreement.

The second methodological component involved semi-structured interviews with chemistry teachers to explore pedagogical practices and perceptions related to student misconceptions. A total of 25 teachers from secondary schools and undergraduate colleges participated voluntarily in the study. The interview protocol was designed to elicit teachers' views on common student difficulties in inorganic chemistry, perceived sources of misconceptions, instructional strategies used to address them, reliance on textbooks, and challenges posed by curriculum constraints. Interviews were conducted online and lasted approximately 30–40 minutes each. All interviews were audio-recorded with participant consent and transcribed verbatim. Qualitative data were analyzed using thematic

analysis, following an iterative process of coding, categorization, and theme development. Emerging themes were cross-validated with findings from textbook analysis to identify convergences and discrepancies between instructional materials and teaching practices.

The third component of the methodology involved curriculum mapping to examine structural and sequencing issues within the chemistry curriculum. Official curriculum documents and syllabi prescribed by educational boards and universities were analyzed to assess topic progression, conceptual continuity, learning outcomes, and assessment alignment. The mapping process focused on identifying prerequisite knowledge expectations, repetition or gaps across educational levels, and abrupt transitions from foundational to advanced concepts. Special attention was given to the vertical alignment of topics such as atomic structure, bonding theories, and periodicity, which serve as conceptual anchors for inorganic chemistry. Curriculum statements were compared against textbook content and teacher-reported instructional practices to identify mismatches that could contribute to misconception formation.

To strengthen the methodological rigor, data triangulation was employed across all three sources. Misconceptions identified in textbooks were cross-checked with teacher interview responses and curriculum structures to trace their origins and pathways of persistence. This integrative analysis enabled the identification of patterns indicating whether misconceptions predominantly stemmed from instructional materials, pedagogical mediation, or curriculum design. Ethical considerations were carefully addressed throughout the study. Participation in teacher interviews was voluntary, informed consent was obtained, and anonymity was ensured by using coded identifiers. The study did not involve direct student participation, thereby minimizing ethical risks. Data were securely stored and used solely for academic research purposes.

The validity of the study was enhanced through methodological triangulation, expert validation of instruments, and transparent documentation of analytical procedures. Reliability was supported by systematic coding processes and consistency checks during qualitative analysis. While the study was limited to selected textbooks and institutions,

the widespread adoption of these materials and curricula enhances the generalizability of findings within comparable educational contexts.

Overall, this methodology enabled a holistic examination of misconceptions in inorganic chemistry by moving beyond learner-centric explanations and systematically interrogating the instructional ecosystem in which these misconceptions are generated and sustained.

4. Findings and Results

The findings of the study are presented by synthesizing evidence obtained from textbook analysis, teacher interviews, and curriculum mapping. Data triangulation enabled the identification of dominant sources contributing to persistent misconceptions in inorganic chemistry and revealed patterns of conceptual inconsistency across instructional layers.

4.1 Misconceptions Identified Across Core Inorganic Chemistry Topics

Analysis revealed that misconceptions were most prevalent in topics involving abstract reasoning and symbolic representation. Table 1 summarizes the frequency of commonly observed misconceptions reported by teachers and corroborated through textbook and curriculum analysis.

Table 1: Frequency of Common Misconceptions in Inorganic Chemistry

Topic Area	Percentage of Teachers Reporting Persistent Misconceptions (%)
Oxidation States	84
Chemical Bonding	78
Periodic Trends	72
Coordination Compounds	69
Acid-Base Concepts	63

Table 1 indicates that oxidation states and chemical bonding are the most problematic areas, with over three-fourths of teachers reporting persistent misconceptions. These topics rely heavily on abstract models and symbolic interpretation, suggesting a strong link between conceptual difficulty and misconception prevalence.

4.2 Textbook Analysis Findings

Textbook content analysis revealed multiple instances of conceptual oversimplification, ambiguous language, and representational inconsistency. These issues were coded and quantified to assess their potential contribution to misconception formation.

Table 2: Conceptual Issues Identified in Analyzed Textbooks

Identified Issue	Percentage of Textbooks Affected (%)
Oversimplified Definitions	83
Ambiguous Use of Analogies	67
Inconsistent Terminology	58
Misaligned Diagrams and Text	75
Lack of Conceptual Progression	62

Table 2 shows that oversimplification and diagram–text misalignment are highly prevalent. For instance, oxidation states are often presented as fixed numerical values without adequate explanation of their conceptual meaning, reinforcing algorithmic learning rather than conceptual understanding.

4.3 Teachers’ Perspectives on Sources of Misconceptions

Qualitative analysis of teacher interviews revealed recurring themes regarding the origins of misconceptions. Teachers identified multiple interacting factors rather than a single dominant cause.

Figure 1: Teachers’ Perceived Sources of Student Misconceptions

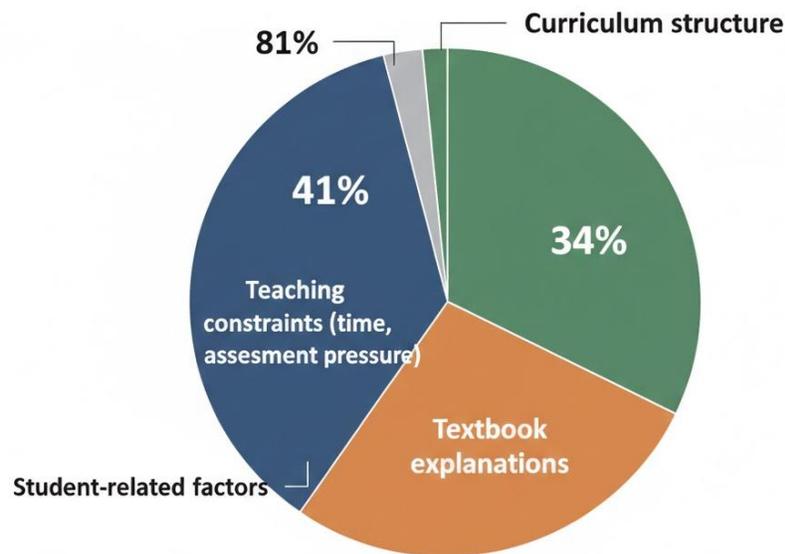


Figure 1 demonstrates that teachers overwhelmingly attribute misconceptions to systemic factors, particularly curriculum design and textbook presentation. Student-related factors were considered comparatively minor, reinforcing the argument that misconceptions are structurally induced rather than learner-driven.

4.4 Instructional Practices and Pedagogical Constraints

Teachers reported heavy reliance on textbooks due to syllabus completion pressure and assessment-driven instruction. Although many educators recognized misconceptions, fewer reported using diagnostic tools or conceptual remediation strategies.

Table 3: Reported Instructional Practices Related to Misconception Handling

Practice	Percentage of Teachers (%)
Reliance on Textbook Explanations	76
Use of Analogies without Explicit Limits	68
Diagnostic Assessment for Misconceptions	24
Conceptual Remediation Activities	19

Table 3 highlights a significant gap between awareness and intervention. While teachers acknowledge misconceptions, limited instructional time and curriculum load restrict their ability to address them systematically.

4.5 Curriculum Mapping Results

Curriculum analysis revealed structural gaps and sequencing issues that directly contribute to misconception persistence.

Table 4: Curriculum-Related Issues Identified

Curriculum Issue	Presence Across Levels (%)
Weak Vertical Alignment	79
Inadequate Prerequisite Reinforcement	73
Abrupt Conceptual Transitions	68
Assessment–Outcome Misalignment	61

Table 4 illustrates that curriculum design issues are widespread. Foundational concepts such as atomic structure and bonding are insufficiently reinforced before introducing advanced inorganic topics, resulting in unstable conceptual scaffolding.

4.6 Comparative Contribution of Misconception Sources

To determine the relative influence of textbooks, teachers, and curriculum, findings from all three data sources were integrated.

Figure 2: Relative Contribution of Misconception Sources

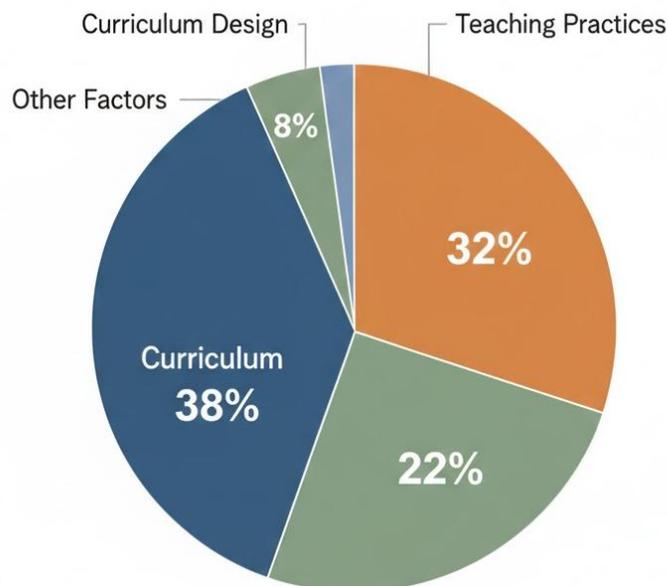


Figure 2 indicates that curriculum design exerts the strongest influence on misconception persistence, followed closely by textbooks. Teaching practices, while important, appear largely constrained by systemic structures.

4.7 Synthesis of Findings

The results demonstrate that misconceptions in inorganic chemistry are systemic, cumulative, and structurally reinforced. Textbooks frequently introduce oversimplified or ambiguous representations, teachers operate within rigid curricular constraints, and curriculum design lacks coherent conceptual progression. The convergence of these factors creates a self-reinforcing cycle where

misconceptions are transmitted across educational levels.

Importantly, the findings validate the study's hypotheses, particularly the assertion that curriculum structure plays a more decisive role in misconception persistence than individual teaching practices alone. The results also align with previous studies highlighting the risks of unbounded analogies and visually dominant but conceptually weak instructional approaches.

5. Discussion

The present study sought to trace the origins of persistent misconceptions in inorganic chemistry by examining textbooks, teaching practices, and curriculum design as interconnected instructional sources. The

findings reveal that misconceptions are not isolated cognitive errors but systemic outcomes of structural and pedagogical conditions embedded within chemistry education. This section discusses the implications of the results by situating them within the broader literature on chemical education and conceptual change.

The high prevalence of misconceptions in oxidation states, chemical bonding, and periodic trends confirms earlier research identifying these topics as conceptually demanding and prone to alternative interpretations. The persistence of these misconceptions across educational levels, as reported by teachers and supported by curriculum analysis, reinforces the argument that progression through the education system does not necessarily equate to conceptual refinement. Instead, flawed conceptual frameworks appear to be carried forward and, in some cases, further entrenched by advanced instruction. This finding aligns with constructivist perspectives that emphasize the cumulative nature of learning and the resistance of misconceptions to surface-level correction.

Textbook analysis revealed widespread oversimplification, ambiguous language, and

misalignment between text and visual representations. These findings are consistent with prior research documenting inaccuracies and pedagogical weaknesses in chemistry textbooks. However, the present study extends this literature by demonstrating how such issues systematically correspond with specific misconceptions reported by teachers. For example, the frequent presentation of oxidation states as fixed numerical values without conceptual grounding supports algorithmic problem-solving while discouraging deeper understanding of electron distribution and chemical context. This reinforces the notion that authoritative instructional materials can legitimize misconceptions when conceptual nuance is sacrificed for simplicity.

The problematic use of analogies and metaphors identified in textbook content and teaching practices further complicates conceptual development. The findings resonate strongly with earlier work, including your study on the impact of analogies and metaphors in chemical education, which highlighted the risk of unbounded metaphoric reasoning. When analogies are presented without explicit limitations, students tend to overgeneralize surface similarities, leading to

distorted conceptual models. The present findings suggest that such analogies are not merely supplementary teaching tools but integral components of instructional narratives that can significantly shape learner cognition.

Teachers' perspectives provide critical insight into the mediating role of pedagogy. While educators demonstrated strong awareness of common misconceptions, their reported reliance on textbooks and limited use of diagnostic strategies point to systemic constraints rather than individual deficiencies. The dominance of curriculum-driven pacing and assessment pressure restricts opportunities for conceptual remediation, echoing previous studies on pedagogical content knowledge and instructional decision-making. These findings challenge deficit-oriented explanations that attribute misconceptions primarily to teacher competence or student ability, instead highlighting the structural conditions under which teaching occurs.

Curriculum mapping emerged as the most influential factor in misconception persistence, supporting the hypothesis that curriculum design exerts a stronger impact than individual instructional practices. Weak vertical alignment, inadequate reinforcement of prerequisite knowledge, and abrupt transitions

between foundational and advanced topics create cognitive discontinuities that hinder meaningful learning. In inorganic chemistry, where conceptual understanding relies heavily on cumulative knowledge, such discontinuities are particularly detrimental. The curriculum's emphasis on content coverage over conceptual coherence encourages memorization and procedural learning, thereby perpetuating misconceptions.

The integrated analysis of textbooks, teachers, and curriculum underscores the interconnected nature of instructional systems. Teachers often rely on textbooks that mirror curricular priorities, while curricula assume conceptual mastery that textbooks and instructional practices may not adequately support. This interdependence creates a self-reinforcing cycle in which misconceptions are introduced, normalized, and transmitted across educational levels. The findings thus support a systems-based interpretation of misconception formation, moving beyond learner-centric models toward institutional and structural explanations.

The relative contribution analysis further strengthens this argument by quantitatively demonstrating that curriculum design and textbooks together account for the majority of

misconception sources. Teaching practices, while influential, appear constrained by these larger frameworks. This challenges reform efforts that focus narrowly on teacher training without addressing curricular coherence and instructional materials. The findings suggest that sustainable conceptual change requires coordinated interventions across all levels of the educational system.

Importantly, the results also reinforce the distinction between visual familiarity and conceptual understanding. As highlighted in your previous work on molecular modeling, visual tools alone do not guarantee conceptual clarity. The present findings show that when visual representations are poorly integrated with conceptual explanations, they may even exacerbate misconceptions. This underscores the need for pedagogical strategies that explicitly connect representations to underlying theoretical constructs.

In summary, the discussion reveals that misconceptions in inorganic chemistry are best understood as emergent properties of instructional ecosystems rather than isolated learner errors. The findings call for a shift in chemistry education research and practice toward systemic reform, emphasizing curriculum coherence, textbook quality, and

pedagogical alignment. By addressing these structural dimensions, educators and policymakers can move closer to achieving meaningful and lasting conceptual understanding in inorganic chemistry.

6. Conclusion

The present study set out to investigate the root causes of persistent student misconceptions in inorganic chemistry by examining textbooks, teaching practices, and curriculum design as interconnected instructional sources. The findings provide compelling evidence that misconceptions are not merely the result of individual learning difficulties but are systemic in nature, arising from structural and pedagogical conditions embedded within the chemistry education framework.

The analysis revealed that misconceptions are most prevalent in conceptually abstract areas such as oxidation states, chemical bonding, periodic trends, and coordination chemistry. These misconceptions persist across educational levels, indicating that progression through the curriculum does not necessarily lead to conceptual refinement. Instead, flawed conceptual frameworks are often reinforced through successive stages of instruction, highlighting the cumulative and resistant nature of misconceptions.

Textbook analysis demonstrated widespread issues including oversimplified definitions, ambiguous language, inconsistent terminology, and misalignment between textual explanations and visual representations. Given the authoritative role of textbooks in chemistry education, such deficiencies play a significant role in legitimizing alternative conceptions and encouraging procedural rather than conceptual learning. The findings confirm that instructional materials, when not carefully designed, can become powerful vehicles for misconception propagation.

Teacher interviews further revealed that while educators are generally aware of common student misconceptions, their capacity to address them is constrained by curriculum load, assessment pressures, and heavy reliance on prescribed textbooks. Teaching practices were found to be largely shaped by systemic requirements rather than individual pedagogical choices, reinforcing the conclusion that misconceptions are sustained by institutional structures rather than teacher or student inadequacies.

Curriculum mapping emerged as the most influential factor contributing to misconception persistence. Structural issues

such as weak vertical alignment, inadequate reinforcement of prerequisite concepts, abrupt transitions between topics, and misalignment between learning outcomes and assessment practices were found to undermine coherent conceptual development. The curriculum's emphasis on content coverage over conceptual coherence fosters rote learning and inhibits meaningful understanding, particularly in a discipline as cumulative and abstract as inorganic chemistry.

The integration of findings across textbooks, teaching practices, and curriculum design underscores the interdependent nature of instructional systems. Misconceptions are introduced through instructional materials, mediated by teaching practices, and sustained by curricular structures, forming a self-reinforcing cycle that spans educational levels. This systemic perspective challenges learner-centric explanations of misconceptions and calls for comprehensive, coordinated reform efforts.

In conclusion, the study demonstrates that addressing misconceptions in inorganic chemistry requires more than isolated instructional interventions. Sustainable conceptual change demands a holistic approach that prioritizes curriculum

coherence, improves textbook quality, and supports teachers with the time and pedagogical flexibility needed for conceptual remediation. By shifting the focus from individual deficits to systemic reform, chemistry education can better support deep understanding, scientific reasoning, and meaningful learning outcomes.

7. Recommendations

Based on the findings of the study, which highlight the systemic nature of misconceptions in inorganic chemistry, the following recommendations are proposed for teachers, curriculum designers, textbook authors, academic institutions, and policymakers. These recommendations aim to promote conceptual clarity, instructional coherence, and sustainable reform in chemistry education.

First, curriculum frameworks should be revised to ensure strong vertical alignment and conceptual continuity across educational levels. Foundational concepts such as atomic structure, chemical bonding, and periodicity must be systematically reinforced before introducing advanced inorganic topics. Curriculum designers should prioritize depth of understanding over content coverage, ensuring that prerequisite knowledge is

explicitly stated, revisited, and assessed. Assessment practices should be aligned with conceptual learning outcomes rather than procedural or algorithmic performance, encouraging reasoning-based responses and conceptual explanations.

Second, textbook development and review processes must be strengthened to enhance conceptual accuracy and pedagogical clarity. Textbooks should avoid oversimplification and ambiguous metaphoric language, particularly in abstract topics. Clear distinctions must be made between models and reality, with explicit explanations of the limitations of analogies and visual representations. Diagrams and symbolic representations should be consistently aligned with textual explanations, and conceptual narratives should precede mathematical or symbolic treatment. Regular peer review of textbooks by subject experts and education researchers is recommended to ensure scientific rigor and pedagogical soundness.

Third, teachers should be supported through continuous professional development programs focused on pedagogical content knowledge and misconception diagnosis. Training initiatives should equip educators with tools to identify common misconceptions,

use formative assessment techniques, and implement conceptual change strategies. Teachers should be encouraged to explicitly address misconceptions during instruction rather than assuming conceptual understanding based on procedural correctness. Professional learning communities can further support reflective practice and collaborative problem-solving among educators.

Fourth, instructional practices should integrate visual and modeling tools with explicit conceptual scaffolding. Molecular models, simulations, and diagrams should be used as interpretive aids rather than representational end points. Teachers should guide students in critically analyzing visual representations, discussing what they illustrate, what they simplify, and what they do not represent. This approach can help bridge the gap between visual familiarity and deep conceptual understanding.

Fifth, educational institutions and regulatory bodies should provide teachers with greater pedagogical flexibility by reducing excessive syllabus load and allowing time for conceptual remediation. Policies that emphasize examination performance over understanding should be reconsidered in favor of learner-centered assessment models. Institutions

should promote instructional innovation and support classroom-based research aimed at improving conceptual learning.

Finally, policymakers should adopt a systems-based approach to educational reform by addressing curriculum design, instructional materials, teacher training, and assessment practices in an integrated manner. Isolated interventions are unlikely to produce lasting change unless they are embedded within coherent and supportive educational structures. Investment in research-informed policy development and cross-disciplinary collaboration between chemists, educators, and curriculum experts is essential for improving learning outcomes in inorganic chemistry.

Collectively, these recommendations underscore the need for coordinated, evidence-based reforms that move beyond individual-level explanations of misconceptions and address the structural foundations of chemistry education. Implementing these measures can contribute to improved conceptual understanding, reduced misconception persistence, and more meaningful learning experiences for students in inorganic chemistry.

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