



Challenges Facing the Learning of General and Inorganic Chemistry Among A-Level Students in Zanzibar, Tanzania

Ochieng O Anthony

Faculty of Science, Department of Life Sciences, Chemistry Unit, Zanzibar University, Zanzibar, Tanzania

Email: d_norbatus@yahoo.com

ORCID: <https://orcid.org/0000-0002-1463-5280>

Web of Science Researcher ID: AFK-9191-2022

Abstract: This study investigated challenges facing the learning of General and Inorganic Chemistry among Advanced Level (A-level) students in Zanzibar, Tanzania, with emphasis on periodic properties, quantum descriptions, chemical bonding, molecular structure, and chemical reactivity. A cross-sectional mixed-methods design was employed in 15 A-level secondary schools in Mjini Magharibi, Zanzibar. The study involved 62 Chemistry students, comprising 32 Form V and 30 Form VI students, and 11 Chemistry teachers. Data were collected using a structured questionnaire, a 10-question conceptual Chemistry achievement test, semi-structured teacher interviews, and classroom observations. Quantitative data were analysed using frequencies, percentages, and comparisons of performance, while qualitative data were analysed thematically and triangulated with quantitative findings. Approximately 15% of students attained the 45% satisfactory threshold on explanatory questions, indicating substantial difficulty in explaining and applying chemical concepts despite evidence of greater familiarity with recognition-based questions. Major challenges involved connecting periodic properties with electronic structure and chemical reactivity, understanding quantum descriptions and orbitals, applying bonding theories, interpreting molecular structures, and explaining chemical reactivity. Students also reported difficulties communicating chemical reasoning in English, limited access to learning resources, and inadequate opportunities for practical learning. The study recommends concept-oriented instruction, use of chemical models, diagnostic and explanatory assessment, increased use of practical and representational learning, improved learning resources, scientific-language support, and continuing professional development for Chemistry teachers.

Keywords: Chemistry, Periodicity, Bonding, Models, Quantum, Reactivity, Learning, Zanzibar

How to cite this work (APA):

Ochieng, O A. (2026). Challenges Facing the Learning of General and Inorganic Chemistry Among A-Level Students in Zanzibar, Tanzania. *Journal of Research Innovation and Implications in Education*, 10(4), 229 – 240. <https://doi.org/10.59765/hsr5>

1. Introduction

General and Inorganic Chemistry provides an important conceptual foundation for understanding the structure of matter, periodic relationships among elements, chemical bonding, molecular structure, inorganic compounds, and chemical reactivity. Learning these areas requires students to coordinate macroscopic observations, submicroscopic explanations, and symbolic representations of chemical phenomena (Laohapornchaiphan & Chenprakhon, 2024; Talanquer, 2011). At Advanced Level (A-level), the increasing

abstraction of Chemistry requires students to move beyond memorisation towards interpretation, explanation, application, and chemical reasoning.

The learning of General and Inorganic Chemistry therefore requires students to develop the ability to relate atomic and electronic structures to observable chemical properties. Such learning involves scientific observation, critical thinking, analytical reasoning, and problem solving (Ochieng et al., 2019). Where these abilities are insufficiently developed, students may rely heavily on memorisation of definitions, trends, rules, and reaction

equations without developing coherent explanations of chemical phenomena.

In Tanzania, Chemistry is an important science subject in Advanced Secondary Education. The Chemistry curriculum expects students to understand relationships between the structure of elements, periodic properties, chemical behaviour, and chemical reactions. The Tanzania Institute of Education (2023) identifies the understanding of periodic trends and changes in the physical and chemical properties of elements as important components of Advanced Level Chemistry. Such expectations require students to understand why chemical properties change across periods and down groups rather than simply memorising the direction of periodic trends.

Periodic properties are among the areas that can present substantial conceptual difficulties. Properties such as atomic radius, ionisation energy, electron affinity, electronegativity, and polarizability require students to relate observable chemical behaviour to effective nuclear charge, electron shielding, electronic configuration, and atomic size. Research has shown that learners may develop misconceptions about periodicity and the factors responsible for periodic trends (Chowdhury, 2022; Rusek et al., 2024). These difficulties are important because periodic properties provide a conceptual basis for understanding bonding and chemical reactivity.

Chemical bonding is another central area of General and Inorganic Chemistry. At A-level, students are expected to understand ionic, covalent, coordinate, and metallic bonding and to relate bonding models to molecular or ionic structures and observable properties. However, chemical bonding has consistently been identified as a conceptually demanding area of Chemistry education (Joki & Aksela, 2018; Tsapalis et al., 2018; Ünal et al., 2006). Students may rely on simplified explanations such as viewing ionic bonding solely as electron transfer and covalent bonding solely as electron sharing, without considering the electrostatic interactions and other factors underlying chemical bonding.

The problem is further complicated when students are required to move between different representations of chemical structures. Chemical information can be represented through electronic configurations, Lewis structures, structural formulae, molecular geometries, orbital representations, and other symbolic or visual models. Difficulties in interpreting and connecting these representations can interfere with students' understanding of molecular structure and chemical properties (Farheen & Lewis, 2021; Wang & Barrow, 2013).

The quantum description of elements represents another important source of conceptual difficulty. Electronic configuration, quantum numbers, atomic orbitals, electron spin, and atomic spectra provide theoretical foundations for understanding periodicity and chemical bonding. However, these concepts are abstract because

atomic orbitals and electron behaviour cannot be directly observed. Students must therefore use models and symbolic representations to construct explanations of phenomena occurring at the atomic and subatomic levels (Cheng, 2018)

The interdependence among these concepts is particularly important. Electronic structure provides a basis for understanding periodic properties; periodic properties contribute to explanations of bonding; bonding and molecular structure influence chemical properties; and these concepts together contribute to understanding chemical reactivity. Consequently, difficulties in one conceptual area may affect learning in another. For example, inadequate understanding of electronic configuration may make it difficult for students to explain periodic trends, while limited understanding of electronegativity and electron distribution may contribute to difficulties in explaining bond polarity and molecular structure.

Despite considerable international research on students' alternative conceptions in Chemistry, much of the available evidence has been generated outside Tanzania. Studies have reported persistent difficulties involving periodicity, chemical bonding, electrostatic interactions, molecular representations, and the interpretation of chemical structures (Chowdhury, 2022; Luxford & Bretz, 2014; Taber, 2019; Vrabec & Prokša, 2016). However, students' learning experiences may differ according to curriculum, instructional practices, teacher preparation, assessment systems, language of instruction, learning resources, and educational context.

1.1 Statement of the Problem

The Tanzanian Advanced Secondary Chemistry curriculum requires students to develop conceptual understanding and apply chemical knowledge to unfamiliar situations. Nevertheless, evidence from classroom practice suggests that some students experience difficulties when required to explain chemical relationships rather than reproduce memorised information. Such difficulties may be particularly important in General and Inorganic Chemistry because several concepts introduced at A-level are highly interconnected.

In Zanzibar, there is limited empirical evidence concerning how A-level students understand these interconnected concepts and the factors that contribute to their learning difficulties. Existing studies have largely examined individual areas of Chemistry or have been conducted in educational contexts outside Tanzania. Consequently, there is a need for context-specific evidence that examines students' understanding of periodic properties, quantum descriptions, chemical bonding, molecular structure, and chemical reactivity as interconnected areas.

The present study therefore investigated challenges facing the learning of General and Inorganic Chemistry

among A-level students in Zanzibar, Tanzania. Particular attention was given to students' conceptual understanding, their ability to explain chemical phenomena, teachers' perceptions of learning difficulties, classroom practices, learning resources, practical exposure, and language-related challenges.

1.2 Purpose of the Study

The purpose of this study was to investigate challenges facing the learning of General and Inorganic Chemistry among A-level students in Zanzibar, Tanzania.

1.3 Research Objectives

The study sought to:

1. examine A-level students' conceptual understanding of selected General and Inorganic Chemistry concepts;
2. identify the major conceptual difficulties experienced by students in learning periodic properties, quantum descriptions, chemical bonding, molecular structure, and chemical reactivity;
3. examine teachers' perceptions of students' difficulties in learning General and Inorganic Chemistry; and
4. identify contextual and instructional factors associated with students' learning difficulties.

2. Literature Review

2.1 Learning Chemistry at Multiple Levels of Representation

Chemistry learning requires students to coordinate three broad levels of representation: macroscopic phenomena, submicroscopic explanations, and symbolic representations (Talanquer, 2011). Students may observe a colour change or precipitate at the macroscopic level, interpret the event in terms of atoms, ions, or molecules at the submicroscopic level, and represent the process through chemical formulae and equations at the symbolic level.

Difficulties arise when students can operate at one level but cannot connect it to another. Laohapornchaiphan and Chenprakhon (2024) emphasised the importance of learning activities that support students in connecting observable phenomena with submicroscopic explanations. This perspective is particularly relevant to General and Inorganic Chemistry because many concepts, including periodicity, bonding, orbital structure, and reactivity, require students to move between different representations.

2.2 Periodic Properties and Conceptual Understanding

The periodic table is not simply a classification system but a framework for explaining and predicting chemical behaviour. Students need to understand how electronic configuration, effective nuclear charge, shielding, and atomic size contribute to periodic trends.

Chowdhury (2022) reported misconceptions concerning periodicity and learners' understanding of the relationships among elements. Rusek et al. (2024) similarly demonstrated that students' ability to work with the periodic table involves more than recalling element positions. Students may know the direction of a trend without being able to explain its underlying mechanism.

This distinction between recall and explanation is important for A-level Chemistry. If students learn periodic trends primarily as rules, they may experience difficulty applying them to unfamiliar elements or using them to explain chemical reactivity.

2.3 Chemical Bonding and Alternative Conceptions

Chemical bonding is one of the most extensively studied areas of Chemistry education. Students frequently develop alternative conceptions concerning ionic and covalent bonding, bond polarity, electronegativity, and electrostatic interactions (Joki & Aksela, 2018; Ünal et al., 2006).

Luxford and Bretz (2014) demonstrated that students may experience difficulties interpreting representations of ionic and covalent bonding. Vrabec and Prokša (2016) also identified misconceptions associated with chemical bonding representations. Such findings suggest that students' difficulties cannot be addressed solely by providing definitions. Instead, students need opportunities to interpret representations and use bonding concepts to explain chemical properties.

Research has also indicated the value of moving beyond simplified bonding rules towards explanations based on electrostatic interactions and other scientifically appropriate models (Joki & Aksela, 2018). For A-level students, this is particularly relevant when explaining polarisation, bond polarity, molecular structure, and chemical reactivity.

2.4 Quantum Description, Atomic Structure and Molecular Representation

Understanding atomic structure provides a conceptual foundation for periodicity and bonding. Students are expected to understand electronic configurations, quantum numbers, orbitals, and electron arrangements and subsequently use this knowledge to explain chemical properties.

Wang and Barrow (2013) demonstrated that students' conceptual frameworks involving atomic structure, periodic variations, chemical bonding, molecular shape, and polarity are interconnected. Students with

fragmented knowledge may correctly reproduce individual concepts while struggling to establish relationships among them.

The problem is particularly apparent when students are required to interpret molecular structures. Moving from electronic configuration to orbital orientation and then to molecular geometry requires coordination of several conceptual models. Research on molecular visualisation has similarly highlighted the importance of supporting students' ability to construct and interpret molecular representations (Alharbi, 2025).

2.5 Research Gap

The reviewed literature demonstrates that conceptual difficulties in periodicity, chemical bonding, atomic structure, and molecular representation are well documented internationally. However, relatively little empirical evidence is available concerning how these difficulties manifest among A-level students in Zanzibar.

Furthermore, much of the existing literature examines individual topics separately. Less attention has been given to the connections among quantum description, electronic configuration, periodic properties, bonding, molecular structure, and chemical reactivity within the Tanzanian A-level context.

The present study addresses this gap by examining these areas collectively and by combining student assessment data with questionnaire responses, teacher interviews, and classroom observations. The mixed-methods approach was intended to identify not only whether students experienced difficulties but also the conceptual and contextual factors that may help explain those difficulties.

3. Methodology

3.1 Research Design

A cross-sectional mixed-methods design was employed. Quantitative data were used to assess students' reported learning experiences and conceptual performance, while qualitative data from teacher interviews and classroom observations were used to provide contextual explanations for the quantitative findings.

3.2 Study Setting

The study was conducted in 15 Advanced Secondary Schools in Mjini Magharibi, Zanzibar. The schools comprised nine government schools and six private schools offering A-level Chemistry.

3.3 Study Population and Sampling

The study population comprised A-level Chemistry students and Chemistry teachers in the selected schools. All 15 eligible schools were included in the study.

The student sample consisted of 62 A-level Chemistry students, including 32 Form V students and 30 Form VI students. Students were selected using simple random sampling from class registers, with representation from participating schools. Eleven Chemistry teachers from participating schools were selected purposively based on their experience teaching A-level Chemistry, seniority, and availability.

Participation was voluntary, and respondents were informed about the purpose and procedures of the study.

3.4 Data Collection Instruments

Data were collected using four instruments:

1. Structured student questionnaire;
2. Chemistry conceptual achievement test;
3. Semi-structured teacher interview guide; and
4. Classroom observation checklist.

The instruments were designed to examine students' learning experiences, conceptual understanding, instructional practices, and contextual factors affecting the learning of General and Inorganic Chemistry.

3.5 Student Questionnaire

The structured questionnaire contained closed- and open-ended questions. It examined students' perceptions of difficult Chemistry topics, learning experiences, availability and use of textbooks, laboratory facilities, language of instruction, mathematical preparedness, prior Chemistry knowledge, time allocated to Chemistry, and preferred assessment formats.

The questionnaire also examined students' perceptions concerning six conceptual domains: periodic properties, quantum descriptions of elements, chemical bonding, atomic spectra, orbitals and their orientation, and chemical reactivity.

3.6 Chemistry Conceptual Achievement Test

A researcher-developed conceptual achievement test was administered to assess students' understanding of General and Inorganic Chemistry. The test consisted of 10 main questions with multiple sub-items covering periodic properties, electronic configuration, quantum numbers, atomic orbitals, chemical bonding, molecular structure, atomic spectra, and chemical reactivity.

The test included selected-response, short-answer, structured, and explanatory items. The questions assessed both factual knowledge and higher-order abilities, including explanation, interpretation, application, and problem solving.

Particular emphasis was placed on students' ability to explain relationships between electronic structure,

periodic properties, bonding, molecular structure, and chemical reactivity. A score of 45% or above was considered satisfactory for the purpose of interpreting the conceptual achievement results.

3.7 Teacher Interviews

Semi-structured interviews were conducted with 11 Chemistry teachers. The interview guide addressed approximately 10 areas, including difficult Chemistry topics, common student misconceptions, instructional approaches, practical work, availability of learning materials, class size, mathematical preparedness, students' prior Chemistry knowledge, language-related challenges, assessment practices, teaching experience, and time allocated to General and Inorganic Chemistry.

The semi-structured format ensured consistency across interviews while allowing teachers to provide detailed explanations based on their classroom experiences.

3.8 Classroom Observations

Classroom observations were conducted using a structured checklist. The observations focused on teaching strategies, student participation, questioning, use of textbooks and instructional materials, demonstrations and practical activities, use of diagrams and molecular models, explanations of abstract concepts, use of the periodic table, and opportunities for students to explain and apply chemical concepts.

Observation data were used to complement questionnaire, achievement-test, and interview findings.

3.9 Validity and Reliability

The research instruments were reviewed by Chemistry educators and Chemistry education experts to assess content validity, clarity, relevance, and alignment with the A-level Chemistry curriculum and study objectives.

The instruments were piloted among students with characteristics similar to those of the study population but who were not included in the final sample. Feedback from the pilot study was used to improve the clarity and appropriateness of the questionnaire and achievement-test items. The conceptual achievement test was also reviewed in relation to item relevance and the established marking criteria.

3.10 Data Analysis

Quantitative data were analysed using descriptive statistics. Frequencies and percentages were used to summarise questionnaire responses and categorical findings. Achievement-test performance was summarised using percentages, with 45% used as the satisfactory threshold. Where appropriate, comparisons of performance across selected groups were conducted using independent-samples t-tests. However, because the present manuscript does not report the complete group

means, standard deviations, confidence intervals, or p-values, these statistics are not reproduced here.

Qualitative data from open-ended questionnaire responses and teacher interviews were analysed thematically. The analysis involved familiarisation with the data, coding, identification of categories, development of themes, review of themes, and interpretation.

3.11 Triangulation

Triangulation was conducted by comparing evidence from student questionnaires, conceptual achievement tests, teacher interviews, and classroom observations. Convergence among data sources was used to strengthen interpretation, while differences were examined for possible contextual explanations.

4. Results and Discussion

4.1 Characteristics of the Study Participants

The study involved 62 A-level Chemistry students from 15 secondary schools in Mjini Magharibi, Zanzibar. Of these, 32 were Form V students and 30 were Form VI students. The study also included 11 Chemistry teachers from participating schools.

The inclusion of students from both Form V and Form VI provided evidence from learners at different stages of A-level Chemistry. The participation of teachers enabled students' reported difficulties and assessment performance to be interpreted alongside classroom experience.

4.2 Students' Conceptual Achievement

The conceptual achievement test showed a substantial difference between students' ability to respond to recognition-oriented questions and their ability to provide explanations. Approximately 15% of students reached the 45% satisfactory threshold on explanatory questions.

This finding suggests that students' difficulties extended beyond factual recall. Some students appeared able to identify or reproduce chemical information but experienced greater difficulty explaining relationships among concepts or applying principles to unfamiliar situations.

The distinction is important because Chemistry learning requires students to coordinate different levels of representation and use conceptual knowledge to explain chemical phenomena (Talanquer, 2011). Thus, conventional recognition-oriented questions may not fully reveal the nature of students' conceptual understanding.

The result also supports previous research showing that students may retain fragmented or alternative conceptions even when they can provide apparently correct answers to selected questions (Taber, 2019; Wang & Barrow, 2013).

4.3 Difficulties with Periodic Properties

Students reported difficulties understanding periodic properties, particularly when required to explain the

reasons underlying periodic trends. Approximately 45% of students reported difficulty understanding periodic properties.

The teachers' accounts supported this finding. Teachers reported difficulties in connecting periodic trends with electronic configuration, atomic structure, and chemical reactivity.

Table 1: Triangulation of Evidence on Students' Learning Difficulties

Key finding	Student questionnaire/test	Teacher interview	Classroom observation	Interpretation
Periodic properties	About 45% reported difficulty with periodic properties	Teachers reported difficulty connecting periodicity with electronic configuration and reactivity	Students experienced difficulty explaining relationships among periodic concepts	Evidence indicates difficulty with conceptual integration
Abstract concepts	Approximately 15% reached the satisfactory threshold on explanatory items	Teachers identified quantum and orbital concepts as particularly difficult	Students showed difficulty explaining abstract concepts	Convergent evidence of abstract conceptual difficulty
Conceptual integration	Students experienced difficulty relating concepts across questions	Teachers reported difficulty transferring knowledge from one topic to another	Limited student explanation of relationships among concepts was observed	Difficulties extended beyond isolated facts
Scientific communication	Students reported difficulty expressing chemical reasoning in English	Teachers identified language as a barrier to explanation	Students sometimes struggled to articulate reasoning orally	Language may compound conceptual-expression difficulties
Assessment format	Students were more comfortable with objective questions	Teachers reported greater student familiarity with examination-oriented tasks	Students were more responsive to structured questioning	Recognition-oriented assessment may be more familiar than explanatory assessment

The finding suggests that students may have learned periodic trends as memorised rules rather than as consequences of electronic structure. Similar concerns have been reported in studies of students' understanding of periodicity (Chowdhury, 2022; Rusek et al., 2024). Teaching should therefore connect periodic trends explicitly to effective nuclear charge, shielding, electronic configuration, and electron–nucleus attraction.

4.4 Difficulties with Quantum Description and Atomic Structure

Teacher interviews identified electronic configuration, quantum descriptions, atomic spectra, orbital structures, and orbital orientation as difficult areas.

Teachers T2, T5, T7, and T11 particularly identified difficulties in understanding quantum descriptions, atomic spectra, electronic configuration, and orbitals. These findings suggest that students may experience difficulties moving from procedural tasks, such as writing electron configurations, towards conceptual explanations of why electronic structure influences chemical behaviour.

The difficulty is understandable because quantum descriptions require students to reason about entities that cannot be directly observed. Students must use symbolic and visual representations to construct models of atomic structure.

The findings are consistent with Wang and Barrow (2013), who reported that students' frameworks

concerning atomic structure, periodic variation, bonding, and molecular shape are interconnected. Consequently, weaknesses in understanding atomic structure may influence students' learning of subsequent topics.

4.5 Difficulties with Chemical Bonding

Chemical bonding emerged as another important area of difficulty. Teachers identified challenges involving ionic and covalent bonding, electronegativity, dipole moments, polarisation, and bonding theories.

Teacher T4 reported difficulty distinguishing electronegativity from dipole moment when students determined ionic and covalent character. Teacher T6 identified difficulties in applying bonding theories to explain chemical bonding.

These findings are consistent with previous research showing persistent alternative conceptions concerning ionic and covalent bonding (Joki & Aksela, 2018; Luxford & Bretz, 2014; Tsapalis et al., 2018; Vrabec & Prokša, 2016).

The findings suggest that students may benefit from learning bonding through explanatory models rather than definitions alone. For example, students should be encouraged to use electronegativity, ionic charge, atomic size, polarisation, and electrostatic interactions to explain differences in bonding behaviour.

4.6 Difficulties with Molecular Structure, VSEPR and Hybridisation

Teachers also reported difficulties with structural elucidation, particularly involving VSEPR theory and hybridisation. Teacher T3 reported difficulties in using VSEPR and hybridisation together to explain molecular structures.

This challenge requires students to integrate electronic configuration, orbital concepts, electron-pair arrangements, and molecular geometry. Simply memorising relationships such as " sp^3 = tetrahedral" may not demonstrate that students understand the reasoning underlying molecular geometry.

Alharbi (2025) emphasised the importance of supporting students' visualisation of molecular geometry. The use of molecular models, diagrams, three-dimensional representations, and guided reasoning may therefore help students connect electronic structure with molecular shape.

4.7 Difficulties Applying Concepts to Chemical Reactivity

Chemical reactivity emerged as an integrative area of difficulty. Teachers reported challenges in connecting periodic properties and bonding with chemical behaviour.

Teacher T1 identified difficulty relating periodic properties to chemical reactions, while T8 reported difficulties in identifying and balancing redox reactions. Teacher T9 identified difficulties relating bonding to chemical reactivity, and T10 reported difficulties concerning metalloid behaviour.

These findings suggest that students may experience difficulty transferring knowledge from one conceptual domain to another. Understanding reactivity requires students to integrate electronic structure, periodic properties, bonding, and other chemical principles rather than rely solely on memorised reaction patterns.

4.8 Language and Scientific Communication

Students reported difficulty communicating chemical reasoning in English. This issue is particularly important when interpreting performance on explanatory questions.

A weak written explanation may reflect both conceptual difficulty and difficulty expressing scientific ideas in the language of instruction. Therefore, an incorrect explanatory response should not automatically be interpreted as evidence that a student has no conceptual understanding.

Teachers should therefore provide structured opportunities for students to develop scientific vocabulary and communicate chemical reasoning. Concept maps, labelled diagrams, oral explanations, sentence structures, and progressively more complex written responses may provide useful support.

4.9 Learning Resources and Practical Exposure

Students and teachers identified limitations concerning textbooks and opportunities for practical learning. Although laboratory facilities were available for relatively simple practical activities, opportunities to use practical work to support abstract conceptual learning appeared limited.

The issue is important because abstract Chemistry concepts can be supported through demonstrations, models, molecular visualisation, and practical investigation. Where students depend heavily on teacher notes because of limited access to textbooks, opportunities for independent exploration may also be constrained.

Learning resources should therefore include adequate textbooks, reference materials, molecular models, periodic tables, diagrams, and appropriate digital resources.

4.10 Classroom Observations

Classroom observations provided contextual evidence that complemented the student assessment and teacher

interviews. The observed learning environment showed greater emphasis on teacher explanations and structured questioning than on extended student explanation and conceptual discussion.

Students participated more readily in structured question-and-answer activities than in tasks requiring extended conceptual explanation. This observation was consistent with the students' preference for objective and structured assessment formats.

The classroom evidence therefore supports the interpretation that students may have greater familiarity with reproduction and recognition of chemical information than with extended conceptual reasoning (Osman, 2013). However, these observations should not be interpreted as an assessment of individual teacher

competence. Rather, they illustrate the instructional conditions within which students were learning.

4.11 Thematic Analysis of Teacher Interviews

Analysis of the 11 teacher interviews generated four broad themes:

1. difficulty understanding abstract chemical concepts;
2. difficulty integrating related chemical concepts;
3. difficulty applying theoretical principles to chemical behaviour; and
4. difficulty communicating and interpreting chemical reasoning.

Table 2: Themes Emerging from Teacher Interviews

Teacher	Main issue reported	Category	Emerging theme
T1	Periodic properties and chemical reactions	Periodicity and reactivity	Integrating periodicity with chemical behaviour
T2	Quantum description and orbital orientation	Atomic structure	Abstract conceptual understanding
T3	VSEPR and hybridisation	Molecular structure	Integrating models to explain structure
T4	Electronegativity and dipole moment	Bond polarity	Conceptual differentiation
T5	Electronic configuration and periodic position	Quantum description/periodicity	Connecting electronic structure with periodicity
T6	Application of bonding theories	Chemical bonding	Understanding abstract bonding models
T7	Quantum description of orbitals	Atomic structure	Abstract quantum concepts
T8	Identification and balancing of redox reactions	Reactivity	Applying chemical principles
T9	Bonding and chemical reactivity	Bonding/reactivity	Integrating concepts
T10	Metalloid behaviour	Periodicity/reactivity	Understanding atypical periodic behaviour
T11	Wave-mechanical description and orbitals	Quantum description	Abstract conceptual understanding

The convergence of teacher perspectives with student assessment results indicates that the learning difficulties were not restricted to individual topics. Instead, students

appeared to experience difficulty establishing relationships among related concepts.

4.12 Triangulation of Quantitative and Qualitative Findings

Table 3: Triangulation of Quantitative and Qualitative Findings

Quantitative finding	Teacher evidence	Integrated interpretation
Difficulty with periodic properties	T1 and T5 identified periodicity and electronic-configuration difficulties	Students may have difficulty connecting periodic trends with electronic structure
Difficulty with quantum description	T2, T5, T7 and T11 identified quantum description, electronic configuration and orbitals	Strong convergence across data sources
Difficulty with bonding	T4 and T6 identified bonding, electronegativity and dipole concepts	Supports conceptual difficulties in bonding
Difficulty with molecular structure	T2 and T3 identified molecular structure, VSEPR and hybridisation	Indicates difficulty integrating structural models
Difficulty with reactivity	T1, T8, T9 and T10 identified reaction, redox and metalloid behaviour	Suggests difficulty applying concepts to chemical behaviour
Low explanatory performance	Teachers repeatedly identified difficulty explaining and applying concepts	Supports a distinction between recall and conceptual reasoning

The triangulated findings indicate that students' difficulties were multidimensional. They involved conceptual understanding, integration of related concepts, scientific communication, instructional practices, and learning resources.

The overall pattern can be represented conceptually as:

Quantum description → Electronic configuration → Periodic properties → Atomic interactions → Bonding → Molecular structure → Chemical reactivity

The evidence suggests that students experienced difficulty when required to move between these interconnected stages. This may explain why students could sometimes recall definitions or identify correct responses while struggling with explanatory questions.

Conceptual Implications of Atomic and Molecular Representations for Chemistry Learning

From our observations and findings, the use of models was absent. The use of atomic and molecular models provides an important conceptual bridge between the macroscopic phenomena observed during chemical reactions and the submicroscopic processes occurring at the level of atoms, ions, electrons, and molecules. At A-level, where students are expected to explain rather than merely recall chemical phenomena, such models can facilitate the development of meaningful relationships between atomic structure, bonding, molecular geometry, chemical properties, and reactivity. By visualising otherwise invisible entities, learners can develop more coherent mental representations of chemical structures and use these representations to interpret observable chemical behaviour (Wu et al, 2001)

Molecular models are particularly valuable for understanding three-dimensional structure, bonding and electron distribution. For example, representations of molecular geometry can help students relate electron-pair arrangements to molecular shape making hybridization and VSEPR theories easy to understand and subsequently to polarity, intermolecular interactions and physical properties. Similarly, atomic models can support understanding of electronic configuration and the role of valence electrons in bond formation and chemical behaviour (Perre et al, 2023). These connections enable learners to progress from memorising structural features to explaining why substances exhibit particular chemical properties.

Models can also strengthen students' understanding of chemical reactivity by providing a visual basis for interpreting bond formation, bond breaking and electron redistribution during reactions (Talanquer, 2018). This is particularly important when learning reaction mechanisms, where the movement of electrons and the interaction of reacting species are not directly observable. Consequently, model-based representations may assist learners in developing predictive reasoning, allowing them to infer likely reaction behaviour from molecular structure rather than relying exclusively on memorised reaction patterns.

The pedagogical value of models therefore lies not simply in their ability to make Chemistry more visual, but in their capacity to connect the macroscopic, submicroscopic and symbolic levels of chemical representation. Effective integration of these levels can help learners interpret chemical equations and experimental observations in terms of underlying particle-level processes. However, models are simplified representations and may themselves generate misconceptions if their limitations are not explicitly

discussed (Traphagen & Minbirole, 2026). Effective instruction should therefore combine model construction and visualisation with explanations, symbolic representations and opportunities for learners to critically interpret what a model represents and what it does not.

5. Conclusion and Recommendations

5.1 Conclusions

The study found that A-level students in Zanzibar experienced substantial challenges in learning General and Inorganic Chemistry. The difficulties were particularly evident when students were required to explain, integrate, and apply chemical concepts rather than simply recognise or reproduce information- rote learning.

Periodic properties, quantum descriptions, electronic configuration, chemical bonding, molecular structure, and chemical reactivity emerged as interconnected areas of difficulty. Approximately 15% of students reached the 45% satisfactory threshold on explanatory questions, indicating that conceptual reasoning presented a greater challenge than recognition-oriented responses.

The findings from students, teachers, and classroom observations converged to indicate that the difficulties involved more than limited factual knowledge. Students experienced difficulty establishing conceptual connections and communicating chemical reasoning. Limited learning resources, practical exposure, and language-related challenges may further contribute to these difficulties.

The study therefore concludes that effective learning of A-level General and Inorganic Chemistry requires greater emphasis on conceptual integration, explanation, application, multiple representations, practical experiences, and scientific communication.

5.2 Recommendations

5.2.1 Strengthen concept-based Chemistry instruction

A-level Chemistry instruction should place greater emphasis on conceptual understanding rather than memorisation of definitions, trends, and rules. Teachers should explicitly establish connections among electronic configuration, periodic properties, chemical bonding, molecular structure, and chemical reactivity.

5.2.2 Increase explanatory and diagnostic assessment

Teachers should incorporate more "why" and "how" questions, structured-response items, concept questions, and diagnostic assessments alongside multiple-choice questions. Such assessment can help distinguish factual recall from genuine conceptual understanding and identify students' alternative conceptions.

5.2.3 Improve teaching of abstract Chemistry concepts

Concepts such as quantum numbers, atomic orbitals, polarisation, VSEPR, and hybridisation should be supported through diagrams, molecular models, simulations, demonstrations, and guided explanations. Students should be encouraged to explain the reasoning behind molecular structures rather than simply memorise associations.

5.2.4 Strengthen practical learning

Schools should increase opportunities for students to connect theoretical Chemistry with observable phenomena. Practical activities should encourage students to predict, observe, explain, and relate experimental observations to chemical principles.

5.2.5 Improve access to learning resources

Schools and educational authorities should strengthen the availability of Chemistry textbooks, reference materials, molecular models, periodic tables, diagrams, and appropriate digital learning resources. Adequate shared learning resources should be available to reduce dependence on individually purchased materials.

5.2.6 Address scientific-language challenges

Teachers should explicitly support students in developing Chemistry-specific vocabulary and communicating scientific reasoning in English. Concept maps, labelled diagrams, guided sentence construction, oral explanations, and structured short responses can help students progressively develop scientific communication.

5.2.7 Strengthen mathematical preparation

Chemistry teachers should provide targeted support for mathematical and symbolic skills required in Chemistry. Relevant quantitative skills should be reinforced within Chemistry lessons rather than assumed to have been fully mastered elsewhere.

5.2.8 Strengthen teacher professional development

Professional development programmes should support A-level Chemistry teachers in concept-oriented instruction, diagnostic assessment, multiple representations, guided inquiry, higher-order questioning, practical learning, and strategies for identifying and addressing students' alternative conceptions.

5.2.9 Review assessment practices

Curriculum developers and examination bodies should maintain an appropriate balance between selected-response and constructed-response assessment. Assessment should provide students with opportunities to interpret, explain, predict, justify, and apply chemical concepts.

5.2.10 Future research

Further studies should involve larger and more geographically diverse samples across Tanzania, including schools in both urban and rural settings. Longitudinal and intervention studies are also recommended to determine whether concept-oriented teaching, improved practical exposure, enhanced learning resources, and scientific-language support lead to measurable improvements in students' conceptual understanding.

References

- Alharbi, A. A. (2025). Cognitive learning approach to enhance university students' visualization of molecular geometry in chemical compounds: A case study in Saudi Arabia. *Journal of Radiation Research and Applied Sciences*, 18(1), Article 101283. <https://doi.org/10.1016/j.jrras.2024.101283>
- Cheng, M. (2018). Students' visualisation of chemical reactions – Insights into the particle model and the atomic model. *Chemistry Education Research and Practice*, 19, 227–239. <https://doi.org/10.1039/C6RP00235H>
- Chowdhury, P. (2022). Learners' misconceptions in periodic table: An analysis of cognitive skills development. *Universal Journal of Educational Research*, 10, 57–66. <https://doi.org/10.13189/ujer.2022.100106>
- Dorji, P., & Chophel, Y. (2022). Rectifying misconceptions on covalent bonding using cooperative learning, concrete models, and computer simulation: A case study. *International Research Journal of Science, Technology, Education, and Management*, 2(2), 1–10. <https://doi.org/10.5281/zenodo.6975643>
- Farheen, A., & Lewis, S. E. (2021). The impact of representations of chemical bonding on students' predictions of chemical properties. *Chemistry Education Research and Practice*, 22(4), 1035–1053. <https://doi.org/10.1039/D1RP00070E>
- Joki, J., & Aksela, M. (2018). The challenges of learning and teaching chemical bonding at different school levels using electrostatic interactions instead of the octet rule as a teaching model. *Chemistry Education Research and Practice*, 19. <https://doi.org/10.1039/C8RP00110C>
- Kazakov, V., Kazakov, V., Meshkov, O., & Yatsenko, A. (2024). "Electronic Structure of Atoms" information system for atomic spectroscopy. *Russian Journal of Physical Chemistry A*, 98. <https://doi.org/10.1134/S0036024424050145>
- Laohapornchaiphan, J., & Chenprakhon, P. (2024). A review of research on learning activities addressing the submicroscopic level in chemistry. *Journal of Chemical Education*, 101(11), 4552–4565.
- Luxford, C. J., & Bretz, S. L. (2014). Development of the Bonding Representations Inventory to identify student misconceptions about covalent and ionic bonding representations. *Journal of Chemical Education*, 91(3), 312–320.
- Müller, C. H., Reiher, M., & Kapur, M. (2024). The multiple student conceptions of the chemical bond in a quantum chemical context. *Journal of Chemical Education*, 101(8), 3039–3049. <https://doi.org/10.1021/acs.jchemed.4c00024>
- Ochieng, O. A., Shaban, H. M., & Nassor, S. M. (2019). A study of performance in chemistry among lower secondary government schools in Zanzibar. *African Journal of Chemical Education*, 9(2)
- Osman, N. (2013). Conceptual understanding in secondary school chemistry: A discussion of the difficulties experienced by students. *American Journal of Applied Sciences*, 10, 433–441. <https://doi.org/10.3844/ajassp.2013.433.441>
- Pierre Nahimana, J., Karegeya, C., Baptiste Nkurunziza, J., Gakuba, E., & Ntihabose, R. (2023). Impact of Low-Cost Atomic Models on Upper Secondary School students' Comprehension of Electronic Configuration and Chemical Bond Concepts in Nyarugenge, Rwanda. *East African Journal of Education and Social Sciences*, 4(3), 240–245. <https://doi.org/10.46606/eajess2023v04i03.0295>
- Rusek, M., Tóthová, M., Chytrý, V., & Řičan, J. (2024). Students' ability to work with the periodic table: The use of three-tier tasks. *Journal of Chemical Education*, 101(11), 4590–4602. <https://doi.org/10.1021/acs.jchemed.4c00485>
- Taber, K. S. (2019). Alternative conceptions and the learning of chemistry. *Israel Journal of Chemistry*, 59, 450–469. <https://doi.org/10.1002/ijch.201800046>
- Talanquer, V. (2018). Importance of understanding fundamental chemical mechanisms. *Journal of Chemical Education*, 95(11), 1905–1911. <https://doi.org/10.1021/acs.jchemed.8b00508>
- Talanquer, V. (2011). Macro, submicro, and symbolic: The many faces of the chemistry "triplet." *International Journal of Science Education*, 33(2), 179–195.

- Tanzania Institute of Education. (2023). *Chemistry syllabus for advanced secondary education: Form V–VI*. Ministry of Education, Science and Technology.
- Thoms, L. J., Blick, G., Schmidt, L., Furrer, F., Purandare, M., Loch, F., & Huwer, J. (2026). Chemistry teachers' perception of students' difficulties in reading and drawing chemical structures. *Journal of Chemical Education*, 103(4), 1723–1742. <https://doi.org/10.1021/acs.jchemed.5c00204>
- Traphagen, S., & Minbiole, J. (2026). Addressing common misconceptions in meiosis. *The American Biology Teacher*, 88(2), 133–135. <https://doi.org/10.1525/abt.2026.88.2.133>
- Tsaparlis, G., Pappa, E. T., & Byers, B. (2018). Teaching and learning chemical bonding: Research-based evidence for misconceptions and conceptual difficulties experienced by students in upper secondary schools and the effect of an enriched text. *Chemistry Education Research and Practice*, 19(4), 1253–1269. <https://doi.org/10.1039/C8RP00035B>
- Ünal, S., Çalık, M., Ayas, A., & Coll, R. K. (2006). A review of chemical bonding studies: Needs, aims, methods of exploring students' conceptions, general knowledge claims and students' alternative conceptions. *Research in Science & Technological Education*, 24(2), 141–172.
- Vrabec, M., & Prokša, M. (2016). Identifying misconceptions related to chemical bonding concepts in the Slovak school system using the Bonding Representations Inventory as a diagnostic tool. *Journal of Chemical Education*, 93(8), 1364–1370. <https://doi.org/10.1021/acs.jchemed.5b00953>
- Wang, C.-Y., & Barrow, L. H. (2013). Exploring conceptual frameworks of models of atomic structures and periodic variations, chemical bonding, and molecular shape and polarity: A comparison of undergraduate general chemistry students with high and low levels of content knowledge. *Chemistry Education Research and Practice*, 14(1), 130–146. <https://doi.org/10.1039/C2RP20116J>
- Wu, H.-K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom. *Journal of Research in Science Teaching*, 38(7), 821–842. <https://doi.org/10.1002/tea.1033>