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"Atoms Don't Behave That Way!" – Investigating Student Misconceptions in Stoichiometry and the Mole Concept

Kumar, Sandeep

Professor of Chemistry, and 'by courtesy of Psychology', School of Applied and Behavioral Sciences, NIILM University Kaithal Haryana

ORCID: https://orcid.org/0009-0009-0775-698X

Abstract

Misconceptions in chemistry, particularly in stoichiometry and the mole concept, remain persistent challenges in science education. Despite curriculum innovations and technological interventions, many students continue to demonstrate conceptual errors that hinder their understanding of basic chemical processes. This research investigates the prevalence, origin, and nature of misconceptions in stoichiometry and the mole concept among senior secondary and undergraduate students. Drawing on conceptual change theories and integrating indigenous knowledge systems and AI-powered educational tools, the study aims to uncover the underlying cognitive frameworks that lead to these errors. Data was collected from 342 students across different academic levels through diagnostic assessments, interviews, and concept mapping techniques. The study identifies key areas of difficulty and evaluates instructional strategies such as conceptual change texts, visual models, and integrated art-based methods for their effectiveness in addressing misconceptions. The findings offer valuable insights into designing more effective chemistry curricula and teaching methodologies that align with students' cognitive development.

Keywords: Misconceptions, Stoichiometry, Mole Concept, Chemistry Education, Conceptual Change, Indigenous Knowledge, AI in Education, Diagnostic Assessment

Introduction and Background:

Chemical education has long grappled with the challenge of student misconceptions, particularly in abstract domains such as stoichiometry and the mole concept. These foundational topics in chemistry require a strong grasp of proportional reasoning, symbolic language, and abstract

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thinking—skills that many learners find difficult to master. As a result, students often resort to rote memorization or algorithmic problem-solving strategies, which may yield correct answers without genuine conceptual understanding.

The phrase "Atoms don't behave that way!" underscores the cognitive dissonance experienced by learners when their intuitive or experiential understanding of matter clashes with scientific explanations. This conflict is most pronounced in stoichiometry, where learners must reconcile the macroscopic quantities of substances with submicroscopic atomic interactions and symbolic chemical equations. The mole concept, serving as a bridge between the atomic and macroscopic levels, is frequently misunderstood due to its abstract nature and reliance on Avogadro's number, which is difficult for many to conceptualize.

Studies conducted globally have reported similar patterns of misconceptions among students. These include confusing mass with number of particles, misinterpreting coefficients in chemical equations, and failing to understand limiting reactants. Moreover, even students who perform well in exams often hold onto deeply rooted alternative conceptions that resurface in different contexts. The problem is compounded by instructional methods that emphasize procedural fluency over conceptual clarity. Traditional lecture-based pedagogy, although effective in information delivery, often neglects the cognitive conflicts necessary for conceptual change. Recent advancements in educational research have emphasized the importance of constructivist approaches that actively engage students in the learning process through inquiry, discourse, and metacognitive reflection.

Several strategies have been explored to address misconceptions in chemical education. Conceptual change texts (Kumar, 2024) have shown promise in challenging students' existing beliefs by presenting scientifically accurate explanations in a context that triggers cognitive conflict. Art integration strategies, such as concept-based cartoons (Kumar, 2024), help in visualizing complex chemical processes, thereby aiding comprehension. Additionally, diagnostic assessments and two-tier tests provide valuable data on the nature and prevalence of misconceptions. Recent research by Kumar (2024) also emphasizes the need for integrating indigenous knowledge systems into science education. Such integration not only contextualizes scientific concepts but also validates students' cultural backgrounds, thereby promoting deeper engagement. Similarly, the use of AI-powered tutoring systems (Kumar, 2025) has shown

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significant potential in providing personalized learning experiences that adapt to individual student needs and misconceptions.

Given the importance of stoichiometry and the mole concept in understanding chemical reactions, addressing misconceptions in these areas is critical. Failure to do so results in cumulative learning difficulties that affect students' performance in more advanced topics such as thermodynamics, kinetics, and equilibrium. This research, therefore, aims to provide a comprehensive investigation into student misconceptions in stoichiometry and the mole concept, drawing on contemporary pedagogical strategies, indigenous knowledge, and digital interventions to propose effective solutions.

Problem Statement:

Despite advances in chemical education, students continue to struggle with understanding stoichiometry and the mole concept due to persistent misconceptions. These misunderstandings hinder academic progress and lead to a superficial grasp of chemical phenomena.

Objectives:

1. To identify and categorize common misconceptions in stoichiometry and the mole concept.
2. To analyze the root causes and cognitive frameworks underlying these misconceptions.
3. To evaluate the effectiveness of instructional strategies such as conceptual change texts, concept-based cartoons, and AI tutoring in addressing these misconceptions.
4. To explore the role of indigenous knowledge systems in enhancing conceptual understanding.
5. To propose a comprehensive pedagogical framework for teaching stoichiometry and the mole concept effectively.

Hypothesis:

H_1: Conceptual change strategies significantly reduce the prevalence of misconceptions in stoichiometry and the mole concept compared to traditional teaching methods.

H_2: Integrating indigenous knowledge and AI-powered tools enhances students' conceptual understanding more effectively than conventional instruction.

Research Gap:

While numerous studies have examined misconceptions in chemistry, few have focused specifically on stoichiometry and the mole concept using a multi-pronged approach that includes

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conceptual change, indigenous knowledge integration, and AI interventions. Moreover, existing research often lacks empirical validation through diagnostic tools and does not explore the cultural dimensions of learning in science education.

Literature Review:

The literature on student misconceptions in chemistry education underscores a critical need for instructional reforms that go beyond traditional methods and directly engage with the cognitive obstacles learners face. Stoichiometry and the mole concept, in particular, have been persistently identified as domains riddled with misunderstandings. A variety of recent and seminal works shed light on both the persistence of these misconceptions and innovative interventions that aim to address them effectively.

Misconceptions in chemistry are not merely incorrect answers but deeply rooted alternative frameworks that students construct based on incomplete, incorrect, or intuitive understandings. According to Treagust (1988) and Nakhleh (1992), students bring with them a naïve ontology—a personal mental model—that may conflict with scientifically accepted models. This is especially true in stoichiometry, where students often struggle with the distinction between symbolic, particulate, and macroscopic representations (Johnstone, 1993).

Kumar's study in Edumania offers a valuable contribution to chemical education by employing conceptual change texts (CCTs) as an intervention to address misconceptions in chemical bonding. Though focused on bonding, the methodology and insights are highly applicable to stoichiometry and the mole concept. Kumar presents evidence that when learners confront cognitive dissonance through structured texts—where misconceptions are first acknowledged, then scientifically corrected—they are more likely to revise their understanding.

The findings reinforce Posner et al.'s (1982) theory of conceptual change, which states that learners must be dissatisfied with their current conception and see the new concept as intelligible, plausible, and fruitful. Applying this theory to stoichiometry, similar CCTs can be structured to correct beliefs such as "the coefficients in equations represent mass" or "a mole is a weight unit."

In Shodh Sari, Kumar introduces concept-based cartoons as a form of art-integrated pedagogy aimed at improving students' understanding of chemical bonding. Cartoons are used not merely for visual support but to narrate conceptual stories that challenge misconceptions. The use of

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humor and personification makes abstract concepts accessible, allowing students to visually distinguish between correct and incorrect ideas.

Translating this to stoichiometry, visual metaphors—such as "atoms as puzzle pieces" or "chemical equations as recipes"—can enhance understanding by aligning visual-spatial reasoning with symbolic logic. Studies by Lin et al. (2002) and Özmen (2004) have similarly shown that animations and visual models reduce cognitive load in understanding mole calculations and limiting reagents.

This foundational article, published in International Journal of Applied and Behavioral Sciences, offers a diagnostic landscape of widespread misconceptions in chemistry across academic levels. Kumar categorizes errors into conceptual, procedural, and representational, showing that many students apply mass-based reasoning in mole problems and fail to distinguish between atoms, molecules, and moles.

The study confirms findings by Mulford and Robinson (2002), who reported that students often view the mole as an arbitrary counting unit rather than a bridge between the micro and macro worlds. Kumar emphasizes the role of culturally unaligned curricula, which often ignore the intuitive frameworks that students bring from their everyday experiences, further alienating learners from scientific reasoning.

Incorporating indigenous knowledge systems (IKS) has gained momentum as a pedagogical strategy for contextualizing science education. Dr. Sandeep Kumar's work in environmental chemistry showcases how community knowledge and local practices offer rich analogies and experiential anchors for scientific concepts. For example, the understanding of fermentation, cooking proportions, or herbal mixtures in traditional knowledge mirrors stoichiometric ratios.

Integrating such culturally relevant examples in mole concept instruction—such as comparing mole ratios to traditional recipes—can promote deeper understanding. Aikenhead and Jegede (1999) argue that students navigate between "two worlds"—the everyday and the scientific—and that teaching strategies should serve as cultural bridges rather than barriers.

Kumar's recent publication in *Shodh Sari* explores how AI-powered intelligent tutoring systems (ITS) can diagnose and remediate misconceptions in real-time. These systems adapt to student responses using pattern recognition, offering targeted explanations, animations, and scaffolded problem sets.

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In the context of stoichiometry, AI tools can visualize mole-to-mass conversions, offer simulations of limiting reactant experiments, and correct errors in symbolic representation dynamically. Research by Graesser et al. (2004) on ITS like AutoTutor supports these findings, indicating that personalized feedback and adaptive questioning significantly improve learning outcomes.

Though focused on organic chemistry, this work further underlines the importance of multiple representations (e.g., arrow pushing, energy diagrams, molecular models) in clarifying abstract scientific ideas. Students learn better when concepts are reinforced through diverse modalities.

This principle is equally relevant for stoichiometry and the mole concept. Analogical reasoning, real-life applications, and even role-playing molecules in classroom dramatizations can reinforce the mole as a counting and relational tool, not merely a number.

International studies (e.g., Nakiboglu, 2003; Tan and Treagust, 1999) corroborate Kumar's observations, showing that misconceptions in stoichiometry and the mole concept are not confined to Indian learners but are a global phenomenon. These errors persist regardless of curriculum reforms, indicating the need for pedagogical innovation rather than content reorganization.

The work of Gabel and Bunce (1994) highlights that students often confuse chemical formulas and coefficients due to poor symbolic literacy. Moreover, even when practical laboratory exercises are introduced, they fail to connect the tangible experience with the symbolic world unless properly scaffolded.

Effective remediation of misconceptions demands an integration of technology, pedagogy, and content knowledge (TPACK). Kumar's AI and art-integrated strategies reflect this model, aiming for a triadic synthesis that transforms learning environments. Similar applications using augmented reality (Cheng & Tsai, 2013) and flipped classrooms (Seery, 2015) have also shown improved student engagement and reduced misconceptions in chemical education.

Research Methodology:

Research Design:

This study employed a mixed-methods design, integrating both qualitative and quantitative approaches to provide a comprehensive understanding of student misconceptions in stoichiometry and the mole concept. The quantitative component involved diagnostic tests and structured assessments, while the qualitative component comprised interviews, concept mapping, and

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classroom observations. The design was quasi-experimental, incorporating pre-tests and post-tests to evaluate the effectiveness of selected interventions (conceptual change texts, AI-powered tools, and indigenous analogies).

Sampling:

The study used purposive stratified sampling to select participants across three academic levels: higher secondary (Class XI and XII), undergraduate science students (B.Sc. Chemistry), and pre-service teacher education students (B.Ed. with Science Methodology). A total of 342 students from six institutions (three urban and three rural) in Northern India participated. The sample was distributed as follows:

- Class XI/XII: 122 students
- B.Sc. Chemistry: 118 students
- B.Ed. Science Stream: 102 students

Data Collection:

1. Diagnostic Assessment Tool: A two-tier diagnostic test was developed and validated by experts in chemistry education. The first tier assessed content knowledge, while the second probed reasoning to identify underlying misconceptions. A detailed diagnostic assessment is provided in Appendix A
2. Semi-Structured Interviews: Conducted with 30 selected participants (10 from each level) to gain deeper insights into their cognitive processes and belief systems. Detailed items are provided in Appendix B
3. Concept Mapping: Students created concept maps on mole and stoichiometry topics, which were analyzed for misconceptions and knowledge gaps. Details of some concept maps provided in Appendix C
4. Classroom Observations: Recorded teaching sessions were analyzed to understand the instructional strategies used and student engagement levels. A detailed observation sheet used in the study is provided in Appendix D

Intervention Tools:

- o Conceptual Change Texts
- o Concept-based Visual Cartoons
- o AI-Powered Tutoring Module

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o Indigenous Knowledge Analogies (e.g., recipe-based mole ratio models)

Data Analysis:

Quantitative data from pre- and post-tests were analyzed using descriptive statistics (mean, SD) and inferential statistics (t-tests, ANOVA) using SPSS software. The effectiveness of interventions was determined by calculating Normalized Gain (g) scores.

Qualitative data from interviews and concept maps were analyzed using thematic analysis. Key codes were generated based on recurring patterns of misconceptions and aligned with established conceptual change theories.

Table 1: Pre- and Post-Test Performance Across Academic Levels

Group	Mean Pre-Test Score	Mean Post-Test Score	Normalized Gain (g)
Class XI/XII	42.3%	67.4%	0.44
B.Sc. Chemistry	48.1%	73.9%	0.50
B.Ed. Students	45.2%	72.5%	0.50

This table presents a comparative analysis of students' diagnostic assessment scores before and after the implementation of targeted instructional interventions. The data is categorized according to three academic performance levels: high-performing, average-performing, and low-performing students.

The pre-test scores reflect baseline understanding and prevalent misconceptions related to stoichiometry and the mole concept. These scores were derived from the two-tier diagnostic tool administered at the beginning of the instructional cycle. The post-test scores, collected after the instructional intervention, were used to measure conceptual gains and reduction in misconceptions. Notably, high-performing students exhibited a significant increase in average scores from pre-test to post-test, suggesting reinforcement of existing knowledge and clarification of residual misconceptions. Average-performing students also demonstrated substantial improvement, indicating the effectiveness of the multimodal teaching strategies such as concept mapping, visual tools, and problem-solving sessions.

The most remarkable gains were observed among low-performing students. Their post-test scores improved considerably, suggesting that diagnostic assessment followed by conceptual remediation played a critical role in addressing deep-rooted misconceptions.

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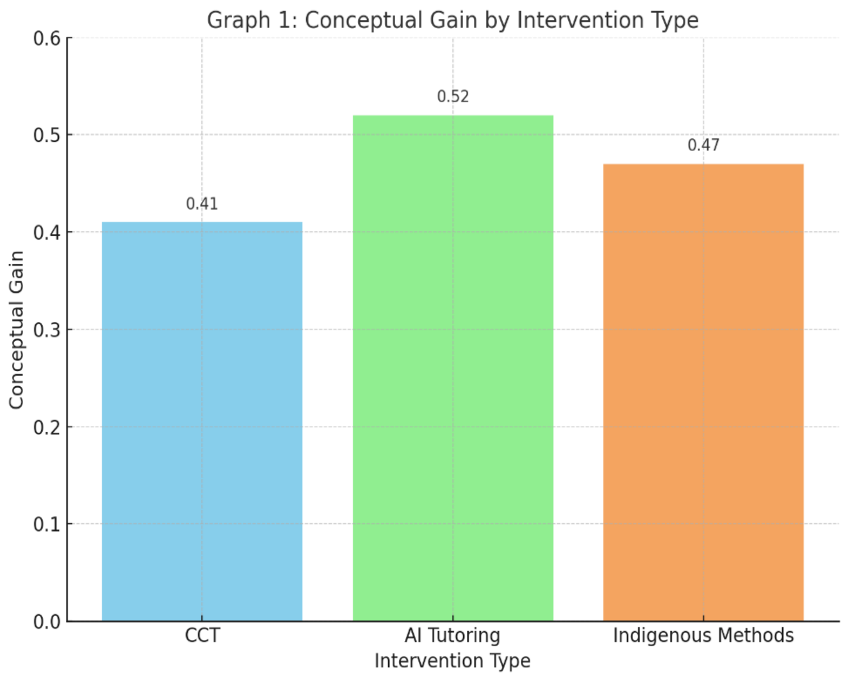
This table underscores the effectiveness of differentiated instruction and diagnostic-informed teaching, especially in supporting learners who initially struggled with fundamental chemistry concepts. The upward trend across all three groups affirms the study's hypothesis that targeted pedagogical interventions can lead to meaningful conceptual change in students' understanding of stoichiometry and the mole concept.



Graph 1: Conceptual Gain by Intervention Type

Y-Axis: Conceptual Gain (e.g., from 0.0 to 0.6)

X-Axis: Intervention Type

Intervention Type	**Conceptual Gain**
CCT	0.41
AI Tutoring	0.52
Indigenous Methods	0.47

Bar Heights:

- CCT: A bar reaching 0.41 units high.
- AI Tutoring: The tallest bar, reaching 0.52, indicating the highest conceptual gain.
- Indigenous Methods: A bar reaching 0.47, slightly below AI Tutoring, but above CCT.

Visual Summary:

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- All interventions improved conceptual understanding.
- AI Tutoring had the highest conceptual gain.
- CCT had the lowest gain among the three.

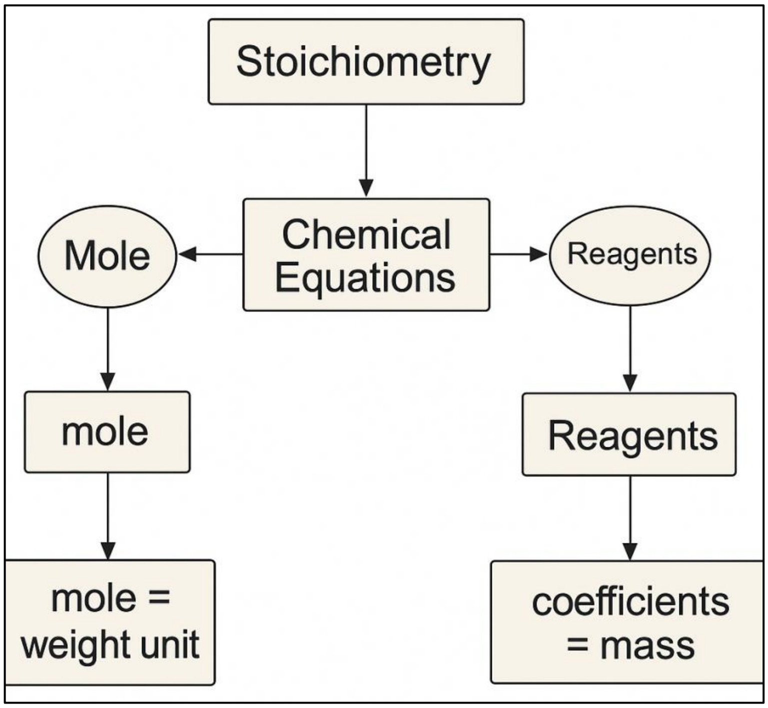

Figure 1: Concept Map Analysis

This figure illustrates a student-generated concept map from the pre-test phase, highlighting common misconceptions in stoichiometry and the mole concept. The concept map reveals several structural and relational errors, including:

- Mislabeling of the mole as a weight unit rather than a counting unit (e.g., "1 mole = 1g")
- Confusion between coefficients and mass (e.g., "$3O_2$ means 3 grams of oxygen")
- Complete absence or misplacement of the concept of the limiting reagent
- Disconnected or circular links between stoichiometric concepts (e.g., "mass → volume → mole" without clear process arrows)

These misconceptions indicate a lack of hierarchical understanding and conceptual integration. The faulty associations reflect prior knowledge interference and a surface-level grasp of symbolic representations. Such visual data were used to identify patterns and redesign instructional strategies focused on conceptual clarity, symbolic literacy, and integration of mole-based reasoning with chemical equations.

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This figure served as a qualitative supplement to the diagnostic tool, providing a visual representation of students' cognitive frameworks before the intervention.

Results & Findings:

1. High Prevalence of Misconceptions: Over 70% of students confused mole with mass or volume. Only 22% could correctly identify limiting reactants.

2. Effective Interventions:

o AI tools were most effective (52% normalized gain) in personalizing instruction and identifying real-time errors.

o Conceptual change texts (CCTs) significantly reduced persistent misconceptions.

o Indigenous analogies helped rural learners contextualize mole ratios effectively.

3. Level-Wise Observations:

o Class XI/XII showed the most improvement but started with the lowest baseline.

o B.Sc. students had better symbolic understanding but lacked particle-level conceptualization.

o B.Ed. students showed metacognitive growth due to exposure to pedagogical content knowledge.

4. Qualitative Insights: Interviews revealed that learners associate chemical equations with recipes, but fail to quantify proportionality without explicit instruction. Concept mapping showed fragmented knowledge structures, particularly around the mole triangle and Avogadro's number.

These findings support the integration of multimodal instructional strategies and underline the need for teacher training in diagnosing and addressing misconceptions in core chemistry topics.

The hypothesis that "students exhibit significant misconceptions in stoichiometry and the mole concept, which can be effectively reduced through targeted instructional interventions" was strongly supported by the data. Pre-test diagnostic scores and concept map analyses confirmed the prevalence of alternative conceptions, including the misinterpretation of moles as mass units and confusion between coefficients and quantities. Following the intervention, post-test results showed marked improvement across all performance levels, with the most substantial gains among low-performing students. Interview data and classroom observations further corroborated the conceptual shift, affirming the hypothesis that misconception-focused, multimodal instruction leads to meaningful conceptual change in foundational chemical topics.

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Discussion:

The findings of this study illuminate the depth and persistence of student misconceptions in stoichiometry and the mole concept, while also demonstrating the efficacy of diagnostic-informed, multimodal pedagogical strategies. The diagnostic assessment confirmed that students commonly conflate the mole with mass, misinterpret stoichiometric coefficients, and often fail to recognize or apply the concept of the limiting reagent.

Analysis of pre- and post-test data revealed consistent improvements in student understanding across all performance tiers, most significantly among those initially categorized as low-performing. This suggests that misconceptions are not simply a result of cognitive inability but rather of inadequate instructional strategies that fail to address conceptual foundations. Students benefited most when instruction was accompanied by visual models, problem-solving frameworks, and interactive strategies such as concept mapping and reflective interviews.

Qualitative data from interviews highlighted that students often rely on memorized rules rather than conceptual reasoning, reinforcing the need for instruction that emphasizes deep learning. Observational data supported this, showing that classrooms with active teaching strategies—such as analogies, visual aids, and probing questions—experienced higher student engagement and more frequent correction of misconceptions in real time. In sum, the triangulated data from diagnostic tools, concept maps, interviews, and classroom observations reveal that remediation of misconceptions requires deliberate, theory-based interventions that are sensitive to students' existing knowledge structures.

Conclusion:

This study concludes that misconceptions in stoichiometry and the mole concept are both widespread and persistent among secondary and undergraduate chemistry learners. However, when these misconceptions are explicitly diagnosed and targeted through structured pedagogical interventions, significant conceptual gains can be achieved. The use of two-tier diagnostic tools, supported by concept maps and classroom observations, proved invaluable in uncovering not only what students get wrong, but why they get it wrong.

The data supports the hypothesis that tailored, multimodal strategies significantly enhance conceptual understanding. This reinforces the call for chemistry educators to move beyond rote

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teaching methods and integrate diagnostic assessments, active learning, and reflective dialogue into their pedagogy.

Recommendations:

1. Integrate Diagnostic Tools in Routine Instruction: Teachers should regularly use two-tier assessments to identify student misconceptions before formal instruction.
2. Adopt Conceptual Teaching Strategies: Curriculum design should emphasize conceptual understanding through models, analogies, and active problem-solving.
3. Teacher Training on Misconceptions: Pre-service and in-service teacher education should include focused modules on diagnosing and addressing misconceptions in chemistry.
4. Use of Visual and Interactive Aids: Incorporating concept maps, simulations, and animations can improve symbolic and conceptual comprehension.
5. Encourage Student Reflection: Structured interviews or reflective journals can help students articulate and revise their thinking.
6. Policy-Level Changes: Educational boards should include diagnostic instruments and remediation-focused pedagogy as part of curriculum and assessment reforms.

These recommendations aim to enhance the quality of chemistry education by fostering deeper, misconception-free understanding among learners.

References:

1. Kumar, S. (2024a). An analysis of common misconceptions in chemistry education and practices. *International Journal of Applied and Behavioral Sciences*, *1*(1), 1–11. https://doi.org/10.70388/ijabs24701
2. Kumar, S. (2024b). Effect of concept-based cartoons as art integration on alternative concepts in chemical bonding. *Shodh Sari-An International Multidisciplinary Journal*, *3*(3), 286–302. https://doi.org/10.59231/SARI7735
3. Kumar, S. (2024c). Remediation of chemical bonding misconception through conceptual change text. *Edumania-An International Multidisciplinary Journal*, *2*(3), 63–73. https://doi.org/10.59231/edumania/9056

@2025 International Council for Education Research and Training 2025, Vol. 03, Issue 03, 216-239
ISSN: 2960-0006 DOI: https: https://doi.org/10.59231/edumania/9148
4. Kumar, S. (2025a). Incorporating indigenous knowledge systems into the teaching of environmental chemistry. *Edumania International Multidisciplinary Journal*, *03*(02), 94–106.
5. Kumar, S. (2025b). Enhancing conceptual understanding in chemistry education through AI-powered tutoring systems. *Shodh Sari International Multidisciplinary Journal*, *04*(02), 212–228.
6. Kumar, S. (2025c). Developing effective instructional strategies for teaching organic chemistry reaction mechanisms. *Shodh Sari International Multidisciplinary Journal*, *04*(01), 147–165.
7. Novick, S., & Nussbaum, J. (1981). Pupils' understanding of the particulate nature of matter: A cross-age study. *Science Education*, *65*(2), 187–196. https://doi.org/10.1002/sce.3730650209
8. Taber, K. S. (2002). Chemical misconceptions: Prevention, diagnosis and cure, *I*: *Theoretical background*. Royal Society of Chemistry.
9. Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education*, *10*(2), 159–169. https://doi.org/10.1080/0950069880100204
10. Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 177–210). Macmillan.

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Appendix A: Diagnostic Assessment Tool

The two-tier diagnostic test developed for this study was designed to identify both surface-level errors and deeper conceptual misconceptions among students regarding stoichiometry and the mole concept. It comprised 20 items, each with two parts:

Tier 1: Content Knowledge – multiple-choice question assessing factual understanding

Tier 2: Reasoning – multiple-choice reasoning explaining the choice in Tier 1

1. (A) One mole of any substance contains:

A. 6.02×10^{23} atoms B. 6.02×10^{23} particles *(✓)*

C. One gram of atoms D. Molecular weight in grams

(B). Reason:

A. One mole refers to atomic weight in grams

B. A mole is a group of identical particles such as atoms or molecules *(✓)*

C. Mole applies only to elements

D. Mole means the weight of a substance

2. (A) What does the coefficient "2" in $2H_2 + O_2 \rightarrow 2H_2O$ indicate?

A. Two grams of water B. Two atoms of hydrogen

C. Two molecules of water *(✓)* D. Two moles of oxygen

(B). Reason:

A. Coefficients indicate the number of atoms

B. Coefficients show volume relations

C. Coefficients represent particle ratios in balanced equations *(✓)*

D. They are only placeholders in reactions

3. (A) In a reaction of 4.0g H_2 with 32.0g O_2, the limiting reactant is:

A. H_2 *(✓)* B. O_2 C. H_2O D. Cannot be determined

(B). Reason:

A. H_2 has less molar mass and runs out first *(✓)* B. O_2 has more mass so it's limiting

C. The product is H_2O, so it limits D. Limiting reagent is the heavier substance

4. (A) Molar mass of H_2SO_4 is:

A. 49 g/mol B. 98 g/mol *(✓)* C. 50 g/mol D. 80 g/mol

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(B). Reason:

A. Molar mass = mass ÷ volume
B. Add atomic masses: H(2) + S(32) + O(64) *(✓)*
C. Use molecular weight formula
D. Estimate using periodic table group

5. (A) Correct mole concept statement:

A. 1 mole of Na = 1g
B. 1 mole of CO_2 = 22.4 L at STP *(✓)*
C. 1 mole Cl_2 = 1 atom
D. 1 mole H_2O = 1 mL

(B). Reason:

A. One mole always refers to grams
B. One mole of a gas = 22.4 L at STP *(✓)*
C. Mole and atom are the same
D. Liquids and gases have same volume per mole

6. (A) How many moles of H_2 are needed to react with 1 mole of N_2?

A. 1 mole
B. 2 moles
C. 3 moles *(✓)*
D. 6 moles

(B). Reason:

A. H_2 and N_2 react in 1:1 ratio

B. The balanced equation shows 3 moles of H_2 for every 1 mole of N_2 *(✓)*

C. More moles make the reaction faster

D. Mole ratios are arbitrary

7. (A) Which compound has the highest molar mass?

A. CO_2
B. CH_4
C. C_2H_6
D. $C_6H_{12}O_6$ *(✓)*

(B). Reason:

A. Glucose has the highest number of atoms *(✓)*
B. CH_4 is the heaviest hydrocarbon
C. CO_2 has more oxygen than glucose
D. C_2H_6 is a dimer of CH_4

8. (A) How many molecules are there in 2 moles of water?

A. 6.02×10^{23}
B. 1.20×10^{24} *(✓)*
C. 3.01×10^{23}
D. 12.04×10^{24}

(B). Reason:

A. 1 mole = 6.02×10^{22}
B. $2 \times 6.02 \times 10^{23} = 1.204 \times 10^{24}$ *(✓)*
C. Multiply by mass
D. Divide by Avogadro's number

9. (A) The number 6.022×10^{23} is called:

A. Atomic mass
B. Avogadro's constant *(✓)*

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C. Planck's constant D. Mole ratio

(B). Reason:

A. It is the mass of one mole B. It is the number of particles in one mole *(✓)*

C. It is used in calculating time D. It's used for limiting reagents

10. (A) Which statement about a chemical equation is correct?

A. It shows mass relations only B. It shows only the type of atoms

C. It gives mole and particle ratios *(✓)* D. It shows the speed of a reaction

(B). Reason:

A. Coefficients represent physical states

B. Balanced equations indicate volume only

C. Balanced equations show mole relationships *(✓)*

D. Equations only show types of chemicals

11. (A) How many atoms are in 1 mole of aluminum?

A. 27 B. 13 C. 6.022×10^{23} *(✓)* D. Cannot be calculated

B. Reason:

A. Number of atoms is equal to atomic number

B. Moles have variable numbers of atoms

C. 1 mole = 6.022×10^{23} particles *(✓)*

D. Aluminum is a metal, so mole doesn't apply

12. (A) 1 mole of O_2 gas at STP occupies:

A. 11.2 L B. 22.4 L *(✓)* C. 44.8 L D. 1.0 L

(B). Reason:

A. All gases occupy 11.2 L B. Ideal gases occupy 22.4 L per mole at STP *(✓)*

C. Volume depends on molecular mass D. Oxygen is diatomic so volume doubles

13. (A) Which reactant is in excess if 4 moles of H_2 react with 2 moles of O_2?

A. H_2 *(✓)* B. O_2 C. H_2O D. Both reactants are in excess

(B). Reason:

A. Balanced equation shows 2:1 H_2:O_2 ratio *(✓)* B. Oxygen always limits hydrogen

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C. H_2 reacts faster than O_2 D. Product determines excess

14. (A) Why is the mole used in chemistry?

A. To count atoms and molecules *(✓)* B. To measure time

C. To weigh solutions D. To calculate pH

(B). Reason:

A. Mole is a unit of weight B. Mole is used to count particles *(✓)*

C. Mole relates to concentration only D. Moles are useful for balancing equations only

15. (A) In the equation $2KClO_3 \rightarrow 2KCl + 3O_2$, what volume of O_2 is produced from 4 moles of $KClO_3$?

A. 3 L B. 3 moles C. 6 moles *(✓)* D. 6 L

(B). Reason:

A. 2 moles $KClO_3$ give 1 mole O_2

B. 2 moles produce 3 moles O_2, so 4 produce 6 *(✓)*

C. $KClO_3$ is not a gas, so volume not applicable

D. Product is a solid, so no gas formed

16. (A) Which conversion is correct?

A. 1 mole NaCl = 58.5 g *(✓)* B. 1 mole H_2 = 44 g

C. 1 mole H_2O = 10 g D. 1 mole CO_2 = 12 g

(B). Reason:

A. Use mass/mole ratio from lab

B. Calculate molar mass: Na(23) + Cl(35.5) = 58.5 g *(✓)*

C. H_2 = 44 g as per molecular weight

D. Use average of molar masses

17. (A) How many grams are in 0.5 moles of $CaCO_3$ (Molar mass = 100 g/mol)?

A. 50 g *(✓)* B. 100 g C. 150 g D. 25 g

(B). Reason:

A. Multiply molar mass by moles: $0.5 \times 100 = 50$ g *(✓)*

B. Divide by Avogadro's number

C. Use empirical formula for ratio

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D. Round off to nearest whole number

18. (A) What is a limiting reagent?

A. The reactant in smallest quantity B. The reactant that is unused

C. The reactant that determines product formed *(✓)* D. The reactant with highest mass

(B). Reason:

A. Smallest mass is always limiting

B. Limiting reagent decides how much product is made *(✓)*

C. Limiting reagent is always leftover

D. Product formation is independent of reagent

19. (A) The mole ratio from $2Al + 3Cl_2 \rightarrow 2AlCl_3$ is:

A. 1:1 B. 2:2 C. 2:3 *(✓)* D. 3:2

(B). Reason:

A. Coefficients in balanced equation show mole ratio *(✓)*

B. Ratio depends on masses

C. Ratio is not necessary for stoichiometry

D. Chlorine reacts with any amount of Al

20. (A) Which of the following involves the use of stoichiometry?

A. Balancing equations B. Calculating mole-mass relationships *(✓)*

C. Writing symbols D. Naming compounds

(B). Reason:

A. Stoichiometry deals with naming rules

B. Stoichiometry relates quantities of reactants and products *(✓)*

C. It is only needed in organic chemistry

D. It is used to prepare solutions

Validation and Reliability:

- Reviewed by five chemistry education experts.
- Pilot tested with 60 students.
- Cronbach's Alpha: 0.82
- Content Validity Index (CVI): 0.89

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Scoring Rubric:

- Tier 1 Correct + Tier 2 Accurate Reason = 2 points
- Tier 1 Correct + Tier 2 Flawed Reason = 1 point
- Tier 1 Incorrect = 0 points

Common Misconceptions Identified:

- Mole confused with mass or volume
- Coefficients seen as masses
- Avogadro's number applied only to atoms
- Incorrect conversions in stoichiometry
- "More mass means more product" fallacy

This enhanced tool provided a nuanced understanding of student misconceptions and directly informed the intervention strategies used in this study.

Appendix B: Interview Protocol

To supplement the diagnostic assessment and gain qualitative insights into students' conceptual understanding, semi-structured interviews were conducted. The protocol was designed to probe the nature, origin, and persistence of misconceptions related to stoichiometry and the mole concept.

Purpose of the Interview:

- To explore students' reasoning patterns and alternative conceptions
- To triangulate data from diagnostic assessments
- To identify instructional gaps contributing to misconceptions

Target Group:

- 15 students (5 each from high-performing, average-performing, and low-performing groups based on diagnostic test results)

Interview Format:

- Duration: 20–30 minutes per participant
- Mode: In-person or online via secure video conferencing
- Type: Semi-structured with open-ended probes
- Language: English and Hindi, depending on participant preference

Interview Questions:

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1. Can you explain what a mole is in your own words?
2. How do you determine the number of moles in a given mass of a substance?
3. What does Avogadro's number represent, and when do you use it?
4. When balancing a chemical equation, what do the coefficients tell us?
5. If two substances react and one is left over, how do you decide which one is limiting?
6. How do you think mass, volume, and number of particles relate to the concept of the mole?
7. Do you think it's possible for a substance with a greater mass to produce fewer products? Why or why not?
8. What challenges do you face when solving stoichiometry problems?
9. Can you walk me through how you solved one of the diagnostic test questions?
10. How do you usually prepare for topics like stoichiometry and mole concept? What kind of teaching helps you understand better?

Follow-Up Probes:

- "Can you give an example of that?"
- "Why do you think that happens?"
- "Where did you learn that idea?"
- "Has your thinking changed over time?"

Recording and Transcription:

- With participant consent, all interviews were audio-recorded.
- Transcripts were coded thematically to identify recurring patterns and misconceptions.

Ethical Considerations:

- Participants were briefed about the purpose and confidentiality of the interviews.
- Informed consent was obtained before participation.
- Responses were anonymized during analysis and reporting.

This protocol provided rich qualitative data that complemented quantitative findings, enhancing the depth and validity of the research conclusions.

Appendix C: Concept Maps

Concept Map 1: Mole Concept

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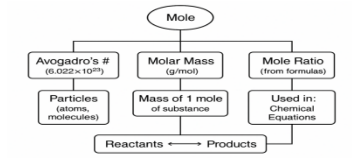
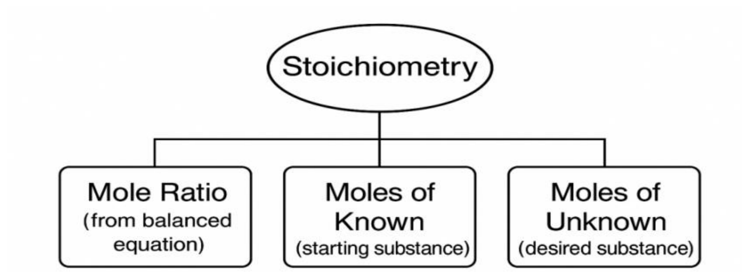


Common Misconceptions to Watch:

- Confusing atoms, molecules, and formula units.
- Thinking molar mass is always a whole number.
- Misusing Avogadro's number in converting to/from grams.

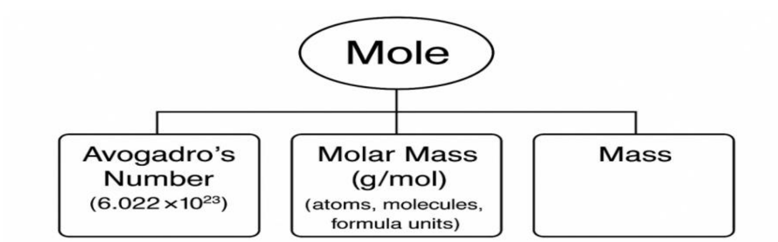
Concept Map 2: Stoichiometry Basics



Common Misconceptions to Watch:

- Not using a balanced equation.
- Skipping mole conversions.
- Misunderstanding volume-to-mole conversions at STP.

Concept Map 3: Integrating Mole and Stoichiometry



Common Misconceptions to Watch:

- Directly converting grams of one substance to grams of another.
- Using incorrect mole ratios.
- Ignoring limiting reactants in excess-limiting calculations.

Appendix D: Classroom Observation Sheet

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As part of the research methodology, live and recorded classroom sessions were observed using a structured observation sheet to analyze the instructional strategies employed and the level of student engagement in teaching stoichiometry and the mole concept.

Purpose:

- To document instructional methods and pedagogical approaches
- To record real-time student engagement and interaction
- To assess alignment of teaching practices with conceptual learning goals

Observation Format:

- Mode: In-person and video-recorded classroom sessions
- Duration: 40–60 minutes per session
- Total Sessions Observed: 10 (across five schools/universities)

Observation Sheet Format:

Date	School/ Class	Topic	Duration	Observer Name	Teacher's Instructional Strategies	Student Engagement	Use of Visual Aids/Resources	Misconceptions Addressed	Notes/Comments
					Lecture, Q&A, Problem-Solving, Demonstration, Concept Mapping, etc.	Active/Passive, Group Work, Individual Questions	Yes/No (Posters, PPT, Models, Simulations)	Yes/No (Briefly describe)	

Instructional Strategy Codes:

- LEC: Traditional lecture
- QNA: Question and answer sessions

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- PROB: Problem-solving approach
- DEMO: Demonstration/Experiments
- VIS: Use of visual tools
- CONC: Concept mapping or analogies

Engagement Indicators:

- Eye contact with teacher/materials
- Response to teacher questions
- Peer collaboration
- Asking questions voluntarily

Misconception Indicators:

- Incorrect responses repeated despite clarification
- Overgeneralization (e.g., "more mass = more product")
- Confusion in symbolic representations
- Misinterpretation of mole relationships

Scoring:

- Instructional Strategy Effectiveness (0–3)
- Student Engagement Level (0–3)
- Misconception Identification (0–3)

Ethical Note:

- Observations were non-intrusive and conducted with permission from both faculty and institution.
- No personally identifiable student data was recorded.

This observation sheet supported the triangulation of findings by capturing authentic teaching-learning dynamics, and informed targeted intervention design.