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# Unveiling Misconceptions in Chemistry: A Review of Causes, Common Patterns, and Levels of Student Understanding

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**Abstract**

The urgency of addressing this issue lies in its long-term impact on students' conceptual development, from secondary school to pre-service teachers. Misconceptions remain a critical issue in chemistry education because they obstruct students' ability to integrate macroscopic, submicroscopic, and symbolic representations, thereby limiting scientific literacy and problem-solving skills.. This review aims to identify chemistry topics most prone to misconceptions, analyze recurring misconception patterns, examine their underlying causes, and assess the reported levels of misunderstanding. A systematic literature review was conducted using the PRISMA 2020 framework, with inclusion criteria focusing on empirical studies published between 2015 and 2025 that employed diagnostic instruments (two-tier, three-tier, four-tier, five-tier, or CRI) and reported data on misconceptions. From an initial 100 records, 30 studies met the criteria and were analyzed. The synthesis shows that the highest average misconception rates occur in buffer solutions, hydrolysis, chemical bonding, and electrolytes (often exceeding 50%), while equilibrium, stoichiometry, thermochemistry, and redox reactions display moderate to lower levels. Common patterns include viewing all hydrogen-containing compounds as acids, assuming ionic bonds form between molecules, perceiving stoichiometry as purely algorithmic, and believing buffer solutions neutralize acids and bases completely. The findings reveal that misconceptions are driven by a combination of prior knowledge, the abstract nature of chemistry, inaccurate textbooks, insufficient teacher explanations, and ambiguous chemical language. The review concludes that misconceptions in chemistry are systematic and persistent, underscoring the need for diagnostic assessments and pedagogical strategies that integrate multiple representations and targeted corrective interventions.

**Keywords:** *Chemistry Misconceptions, Diagnostic Instruments, Buffer Solutions, Chemical Bonding, Systematic Review*

## Introduction

Chemistry, as a central discipline of science, plays a crucial role in bridging the understanding of matter from the macroscopic world that students can observe to the submicroscopic and symbolic levels that require abstract reasoning. This triangulation among the three levels—macroscopic, submicroscopic, and symbolic—is vital, as many students find the complexities of chemistry particularly challenging due to the abstract nature of the concepts involved (Lavi et al., 2019; Thomas, 2017). Chemistry is widely regarded as a difficult subject for learners across different educational stages, evidenced by various studies highlighting persistent misconceptions among students, which are not only prevalent but also resistant to change (Ahmed et al., 2019). Misconceptions, defined as scientifically inaccurate conceptions that students believe to be correct, significantly hinder students' understanding and learning (Akamatsu et al., 2019). One of the persistent challenges in chemistry education is the

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prevalence of misconceptions. These misconceptions often arise from the interplay between students' prior knowledge, the abstract nature of chemistry concepts, and instructional practices that emphasize procedures over understanding. As a result, learners may persist in holding scientifically inaccurate ideas even when confronted with correct explanations, leading to long-term barriers in conceptual development. Therefore, addressing misconceptions in chemistry is not only essential for improving academic performance but also for fostering scientific literacy and critical thinking skills.

Research has shown that these misunderstandings are often deeply rooted and can stem from prior knowledge or common-sense reasoning that conflicts with scientific principles (Балашов et al., 2022). For instance, students frequently carry over misconceptions from their previous learning experiences, thereby creating barriers to new concepts and complicating the learning of higher-order thinking skills (Tawanda & Mudau, 2024). Misconceptions are not merely temporary errors but represent a fundamental misunderstanding that can obstruct meaningful learning (Sari et al., 2019). Additionally, studies indicate that misconceptions manifest in various chemistry topics, such as acid-base chemistry and chemical bonding, highlighting the diverse challenges educators face in addressing these erroneous beliefs (Mathabathe & Potgieter, 2017). Furthermore, research emphasizes the crucial need for educators to identify and modify students' misconceptions. Effective pedagogical strategies, including diagnostic tests and metacognitive skill instruction, have been found to reduce misconceptions and enhance conceptual understanding (Parlan et al., 2018). There is also a call for educators to engage in comprehensive approaches that address not only student misconceptions but also foster an environment of inquiry and conceptual change (Şen, 2016).

Therefore, addressing misconceptions is paramount for facilitating meaningful learning and supporting the development of higher-order thinking skills in chemistry education (Merilia, 2019).Extensive research over the past decades has demonstrated that misconceptions occur across nearly all major areas of chemistry, including chemical bonding, acids and bases, buffer solutions, equilibrium, stoichiometry, electrolytes, redox reactions, thermochemistry, and hydrolysis (Balqees et al., 2023; Djarwo & Kafiar, 2023). These misconceptions not only hinder the acquisition of new knowledge but also have the potential to be carried forward to higher levels of education, affecting pre-service teachers, undergraduate students, and even practicing teachers (Omilani & Elebute, 2020; Syahrial et al., 2023; Widarti et al., 2017). As such, misconceptions in chemistry are not isolated incidents but systemic issues that need to be addressed comprehensively (Adu-Gyamfi & Asaki, 2022; Erman, 2016; Putri et al., 2021).The urgency of studying misconceptions lies in their long-term impact on students' scientific literacy and problem-solving skills.

Students who hold persistent misconceptions often fail to apply scientific reasoning correctly, misinterpret experimental results, and struggle to connect concepts across different domains of chemistry. In the context of modern education, where critical thinking and conceptual understanding are essential, addressing misconceptions is a priority for educators, curriculum designers, and researchers alike. While numerous studies have investigated misconceptions in specific chemistry topics, there remains a need for a systematic synthesis that not only catalogs where misconceptions occur but also explores the causes, recurring patterns, and levels at which they manifest. Previous reviews often focus on single topics or diagnostic methods, offering valuable insights but are limited in scope (Golestaneh & Mousavi, 2024; Prodjosantoso et al., 2019). A broader synthesis is necessary to provide a holistic understanding of the misconception landscape in chemistry education and to identify cross-cutting themes that influence learning outcomes (Hunter et al., 2022; Toczkowski & Ralle, 2015).

Such a synthesis can highlight not only the most problematic areas of student understanding but also reveal how different factors interact to reinforce persistent misconceptions. In doing so, it provides a stronger evidence base for developing targeted pedagogical interventions and refining curriculum design in chemistry education. This article addresses that gap by conducting a systematic literature review of misconceptions in chemistry reported in studies published between 2015 and 2025. Specifically, the review aims to: (1) identify the chemistry topics most susceptible to misconceptions, (2) analyze the common patterns of misconceptions that recur across studies, (3) examine the underlying causes reported in the literature, and (4) assess the levels of misconceptions as identified by diagnostic instruments. Through this synthesis, the article seeks to provide educators and researchers with a clearer map of where and why misconceptions occur, and how they can be effectively addressed in teaching and assessment practices. Ultimately, this review contributes to advancing the discourse in chemistry education by unveiling the complex interplay between causes, patterns, and levels of misconceptions.

By highlighting not only what students misunderstand but also why and to what extent, this work aims to inform the design of instructional strategies that are more responsive to students' conceptual needs and that foster deeper, more accurate understanding of chemistry. The objective of this review is to provide a comprehensive synthesis of research on chemistry misconceptions by systematically mapping the topics most susceptible to misunderstandings, analyzing recurring misconception patterns across studies, examining the underlying causes reported in the literature, and evaluating the levels of misconceptions identified through various diagnostic instruments. Through this analysis, the review seeks to offer educators and researchers a clearer understanding of where and why misconceptions occur in chemistry education, as well as practical insights for designing effective instructional strategies and assessments to address these persistent challenges.

## Method

### *Review Protocol*

This study employed a Systematic Literature Review (SLR) guided by the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure methodological rigor, transparency, and reproducibility. A detailed review protocol was developed prior to the review process, outlining the research objectives, inclusion and exclusion criteria, data items, and analysis plan. The review questions were structured using the PICo framework (Population – Issue – Context), as follows:

a. Population: students and pre-service teachers involved in chemistry learning;
b. Issue: misconceptions identified through diagnostic instruments;
c. Context: empirical studies in chemistry education published between 2015 and 2025.

### *Data Sources and Search Strategy*

Relevant studies were collected from four major databases: Scopus, ERIC, Google Scholar, and Sinta-indexed national journals. The literature search was conducted between January and March 2025, using Boolean operators and customized keyword combinations for each database. The general search terms included the phrases *"chemistry misconceptions"* or *"miskonsepsi kimia"* combined with *"diagnostic test"*, *"two-tier"*, *"three-tier"*, *"four-tier"*, *"five-tier"*, or *"Certainty of Response Index (CRI)"*. Filters were applied to limit the results to studies published between 2015 and 2025 and written in English or Indonesian. In addition to database searching, backward and forward citation tracking was performed on key articles to identify additional relevant studies not captured by the initial search. The final database search was completed on March 10, 2025.

### *Inclusion and Exclusion Criteria*

Studies were included if they: 1) Focused specifically on chemistry misconceptions at any educational level; 2) Used diagnostic instruments (two-tier, three-tier, four-tier, five-tier, or Certainty of Response Index/CRI); 3) Reported quantitative data (percentages or levels of misconceptions) and/or qualitative analysis of causes; 4) Were empirical and peer-reviewed, published between 2015 and 2025. Studies were excluded if they: 1) Addressed general learning difficulties without specific reference to misconceptions; 2) Focused on other disciplines (physics, biology, mathematics); or. 3) Were non-empirical (e.g., opinion papers, essays, editorials, or literature reviews without data).

### *Study Selection and Reliability*

All retrieved records were managed using **Zotero** reference management software. Two independent reviewers conducted the title, abstract, and full-text screening. Disagreements were resolved through discussion until consensus was achieved. The inter-rater reliability was calculated using Cohen's $\kappa = 0.87$, indicating a strong level of agreement. The study selection process followed four PRISMA stages: identification, screening, eligibility, and inclusion.

### *Quality Appraisal*

To ensure methodological soundness and minimize bias, all included studies were appraised using standardized instruments: 1) Quantitative and cross-sectional studies: evaluated using the JBI Analytical Cross-Sectional Checklist; 2) Mixed-methods studies: assessed using the Mixed Methods Appraisal Tool (MMAT, 2018). Each study was categorized as High, Moderate, or Low quality. A sensitivity analysis was performed to verify that excluding low-quality studies did not significantly alter the synthesis outcomes.

## Results

### *Characteristics of Included Studies and Misconception Pattern*

A total of thirty empirical studies published between 2015 and 2025 were systematically reviewed and synthesized to identify patterns, levels, and sources of misconceptions in chemistry learning. The studies were selected based on their methodological relevance, use of diagnostic instruments, and representativeness across key chemistry topics, including chemical bonding, acid–base reactions, buffer solutions, equilibrium, stoichiometry, redox reactions, electrolytes, and thermochemistry. Each study applied diagnostic approaches such as two-tier, three-tier, four-tier, five-tier tests, or the Certainty of Response Index (CRI) to detect and classify students' misconceptions. The details of the reviewed studies—including authors, year of publication, context, diagnostic tools used, percentage of misconceptions, main patterns, and DOI—are summarized in Table 1

***Table 1.*** *Summary of Misconceptions in Chemistry Learning by Topic*

| No | Author(s) & Year | Country / Level | Diagnostic Instrument | % Misconception / Range | Main Misconception Pattern |
|---|---|---|---|---|---|
| 1 | Widarti et al. (2017) | Indonesia / Undergraduate | CRI | 52 % | Buffers neutralize acids & bases completely |
| 2 | Ballester Pérez et al. (2017) | Spain / High & Univ. | Two-tier | 45 % | Confused ionic vs intermolecular bonds |
| 3 | Okmarisa & Hasmina (2021) | Indonesia / High school | Four-tier | 48 % | Electrolyte / nonelectrolyte distinction |
| 4 | Zuhullaili et al. (2022) | Indonesia / High school | Two-tier | 42 % | Oxidation–reduction half-reaction confusion |
| 5 | Milenković et al. (2016) | Serbia / Junior high | Two-tier | 43 % | Misread competition bonding items |
| 6 | Islami et al. (2018) | Indonesia / High school | Four-tier | 30 % | Bond type from electronegativity |
| 7 | Sitorus & Dalimunthe (2024) | Indonesia / High school | Five-tier | 12 % | Misapplied Le Chatelier principle |
| 8 | Apriadi et al. (2018) | Indonesia / High school | CRI | 22 % | Redox concept misunderstanding |
| 9 | Gultom et al. (2023) | Indonesia / High school | Two-tier | 46 % | Confusion in bond polarity & shape |
| 10 | Pikoli (2018) | Indonesia / University | Essay + Interview | 40 % | Ionic vs covalent formation |
| 11 | Anugrah (2019) | Indonesia / High school | Mixed (two/three-tier) | 37 % | Stoichiometry seen as computation |
| 12 | Awwalin & Nugroho (2024) | Indonesia / High school | Five-tier | 41 % | Buffer mechanism & component logic |
| 13 | Isminiarti et al. (2021) | Indonesia / High school | CRI | 25 % | Acid–base strength misconceptions |
| 14 | Agatha et al. (2022) | Indonesia / University | Two-tier | 14 % | Equilibrium constant misused |
| 15 | Imaduddin (2018) | Indonesia / University | Diagnostic essay | 97 % | Sub-microscopic solution level gaps |
| 16 | Arsyad et al. (2016) | Indonesia / High school | CRI + Interview | 23 % | Hydrolysis of salt concept errors |
| 17 | Stephanie et al. (2019) | Indonesia / High & Univ. | Two-tier | 25 % | pH and composition of buffers |
| 18 | Sugiyarto & Heru (2013) | Indonesia / Textbook study | Content analysis | — | Incorrect textbook acid-base & redox |
| 19 | Arif et al. (2020) | Indonesia / High school | CRI | 33 % | Misjudged pH and neutral solution |
| 20 | Noviani & Istiyadji (2017) | Indonesia / High school | Two-tier | 51 % | Bonding–prerequisite knowledge link |
| 21 | Jannah et al. (2016) | Indonesia / High school | CRI | 46 % | Buffer pH & work mechanism |
| 22 | Amry et al. (2017) | Indonesia / High school | Two-tier | 38 % | Acid–base under DSLM vs traditional |
| 23 | Sihaloho et al. (2021) | Indonesia / High school | Two-tier | 92 % (low score rate) | Exothermic vs endothermic |
| 24 | Nugrohadi & Chasanah (2022) | Indonesia / High school | Multiple-choice diagnostic | 16 % | Redox auto-reaction confusion |

| No | Author(s) & Year | Country / Level | Diagnostic Instrument | % Misconception / Range | Main Misconception Pattern |
|---|---|---|---|---|---|
| 25 | Hanna Grace S. et al. (2022) | Indonesia / High school | Two-tier | 39–56 % | Electrolyte vs nonelectrolyte distinction |
| 26 | Wahyuni et al. (2021) | Indonesia / High school | Four-tier | 32 % | Thermochemistry conceptual shift |
| 27 | Ni Ngh. Sangging Apriadi et al. (2018) | Indonesia / High school | CRI | 21 % | Oxidation–reduction transfer error |
| 28 | Sururin et al. (2021) | Indonesia / High school | Two-tier | 29 % | Acid–base neutralization idea |
| 29 | Ismiwati et al. (2018) | Indonesia / High school | CRI | 40 % | Misjudging pH range & ionization |
| 30 | Wahyu et al. (2023) | Indonesia / Pre-service teacher | Four-tier | 34 % | Multi-representation bonding confusion |

In addition to summarizing the characteristics of the included studies, it is equally important to identify the recurring misconception patterns reported across different topics in chemistry learning. Mapping these patterns provides a deeper understanding of how students conceptualize core chemical concepts incorrectly and why such misunderstandings persist despite formal instruction. The analysis reveals that misconceptions are not randomly distributed but tend to cluster around specific topics such as chemical bonding, acids and bases, buffer solutions, stoichiometry, equilibrium, electrolytes, redox reactions, and thermochemistry. Presenting these patterns allows us to highlight the most critical areas where targeted interventions are needed and to connect the diversity of misconceptions with their underlying causes and levels of severity.

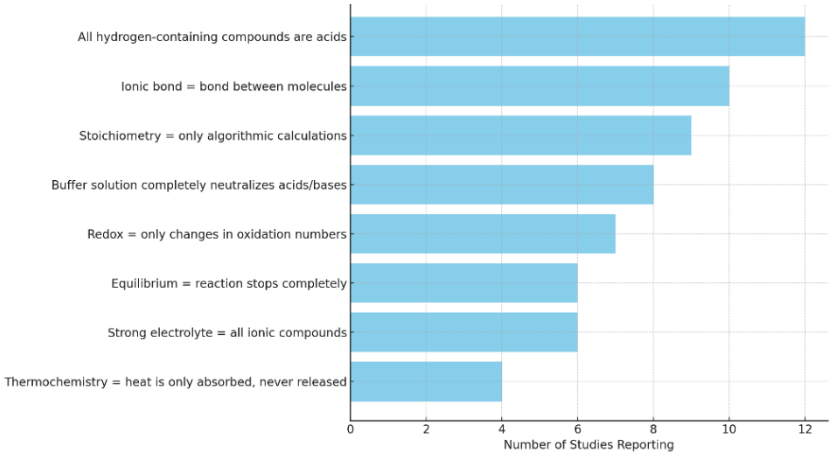


***Figure 1.*** *Most Frequent Misconception Patterns Reported in Chemistry Education Studies*

Figure 1 presents the most frequent misconception patterns identified in chemistry education studies between 2015 and 2025. The most dominant patterns include the assumption that all hydrogen-containing compounds are acids, the belief that ionic bonds occur between molecules rather than between ions, and the tendency to view stoichiometry as merely algorithmic calculations without understanding the underlying mole concept. Another major misconception shown in the figure is the notion that buffer solutions neutralize acids and bases completely, which indicates students' reliance on oversimplified textbook explanations and their struggle to connect symbolic equations with particle-level dynamics.

These recurring patterns highlight that misconceptions in chemistry are not random but systemic, emerging consistently across different topics, populations, and diagnostic instruments. The figure emphasizes that such misunderstandings are rooted in prior knowledge, ambiguous language, and abstract concepts that are difficult to visualize. By mapping these misconception patterns, Figure 1 provides insight into the most critical areas where students experience persistent difficulties, thereby guiding educators to design targeted interventions and more effective instructional strategies.

### *Distribution of Misconception Levels Across Chemistry Topics*

To better illustrate the extent of misconceptions across different areas of chemistry, the average levels of misconceptions reported in the selected studies were calculated and presented. This visualization provides an overview of which topics tend to generate the highest misconception rates and which ones appear less problematic. By comparing these averages, it becomes possible to identify priority areas in chemistry learning where students most often struggle to construct scientifically accurate conceptions.

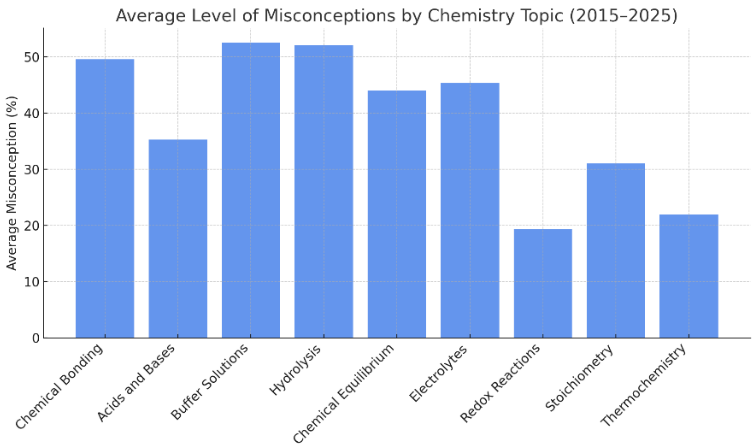


***Figure 2.*** *Average Level of Misconceptions by Chemistry Topic (2015 – 2025)*

As shown in the figure 2, the levels of misconceptions vary significantly among different chemistry topics. Some concepts are consistently associated with higher percentages of misconceptions, while others show relatively lower levels. These variations highlight the importance of examining not only the presence of misconceptions but also their distribution across topics, which will be discussed further in the following section.

### *Causes of Misconceptions*

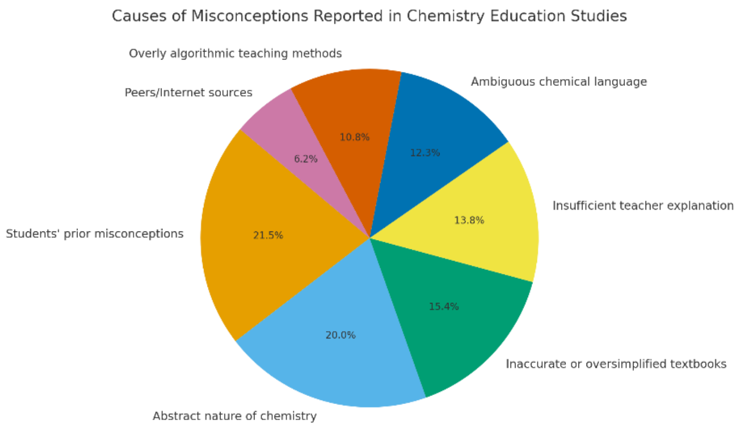


***Figure 3.*** *Causes of Misconceptions Reported iin Chemistry Education Studies*

In addition to identifying the prevalence of misconceptions across chemistry topics, it is also essential to examine the underlying factors that contribute to their occurrence. Understanding these causes provides valuable insights into why misconceptions persist and why they are often resistant to change. The selected studies reported a range of contributing factors, which can be grouped into student-related, teacher-related, and material-related categories. The following chart summarizes the most frequently mentioned causes of misconceptions reported in the literature.

As illustrated in the figure, student-related factors, particularly prior misconceptions, emerge as the most dominant cause, followed by the abstract nature of chemistry concepts. Textbook inaccuracies, insufficient teacher explanations, and ambiguous use of chemical language were also frequently reported. While less prominent, factors such as overly algorithmic teaching methods and peer or Internet influence were also identified. These findings provide a general overview of the factors that shape students' understanding of chemistry concepts and will serve as the basis for further analysis in the discussion section.

## Discussion

### *Distribution of Misconception Levels Across Chemistry Topics*

The synthesis of thirty selected studies reveals significant variation in the levels of misconceptions across major topics in chemistry. On average, the highest misconception levels are concentrated in buffer solutions, hydrolysis, chemical bonding, and electrolytes, while relatively lower levels are observed in redox reactions, stoichiometry, and thermochemistry. This variation suggests that certain concepts in chemistry are more prone to misunderstanding due to their abstract nature and the multiple representational levels required for mastery. Chemical bonding emerges as one of the most problematic areas, with misconception levels ranging from moderate to high. Students commonly mistake ionic bonds for intermolecular forces and demonstrate persistent difficulties with Lewis structures, polarity, and hybridization. These findings are consistent across multiple instruments, including two-tier, three-tier, and four-tier tests, indicating the resilience of misconceptions even after repeated instruction. The results suggest that symbolic representations alone are insufficient and that students require stronger connections between macroscopic observations, submicroscopic models, and symbolic equations.

Similarly, buffer solutions report consistently high levels of misconceptions, particularly regarding pH stability. Students frequently assume that buffer solutions neutralize added acids or bases completely, or miscalculate pH changes when small amounts of strong acids or bases are introduced. The use of advanced diagnostic tools, such as four-tier and five-tier tests, reveals not only the misconceptions but also the reasoning behind them, including reliance on flawed textbook explanations and inadequate microscopic visualization. These findings highlight the urgent need for instructional interventions that explicitly address the dynamic nature of buffer systems.

Hydrolysis and equilibrium exhibit moderate to high levels of misconceptions. In hydrolysis, students often struggle to relate ionization constants (Ka and Kb) to observable pH changes, which reflects a more general difficulty in linking symbolic formulas to particle-level reasoning (Golestaneh & Mousavi, 2024). Misconceptions in equilibrium often include the false belief that reactions cease entirely at equilibrium and misunderstandings related to Le Chatelier's principle and the interpretation of equilibrium constants (Thompson et al., 2023). These misunderstandings highlight the challenges inherent in teaching abstract, dynamic processes that lack clear macroscopic analogies and underscore the necessity for employing innovative instructional strategies, such as concept mapping or computer simulations, to enhance conceptual understanding among students (Etokeren & Abosede, 2022; Kaya, 2023). Addressing these misconceptions effectively requires educators to utilize a multifaceted approach incorporating both foundational knowledge and targeted pedagogical strategies to combat persistent errors in reasoning (Adu-Gyamfi & Asaki, 2022).

In contrast, electrolytes show moderate to high misconception levels, mainly due to the oversimplified belief that all ionic compounds are strong electrolytes. Students tend to classify substances algorithmically rather than conceptually, which prevents them from recognizing exceptions and developing particle-level understanding. On the other hand, redox reactions and thermochemistry report lower misconception levels, possibly because they rely more on algorithmic procedures (e.g., assigning oxidation numbers, applying enthalpy calculations) that are easier for students to memorize and apply, even without deep conceptual understanding. Nevertheless, persistent errors such as confusing electron transfer with oxidation number changes or mixing up heat and temperature indicate that these topics still require conceptual reinforcement.

Stoichiometry occupies a middle position, with misconceptions typically arising from the tendency to treat it as a purely computational exercise. Students often rely on algorithmic problem-solving without understanding the mole concept, limiting reagent, or the proportional reasoning that underpins stoichiometric calculations. This reinforces the idea that algorithmic teaching approaches may provide short-term performance but fail to address long-term conceptual growth. In addition to the differences across topics, the review also highlights recurring misconception patterns that cut across multiple areas of chemistry. As shown in Figure 1. Most Frequent Misconception Patterns Reported in Chemistry Education Studies, several patterns emerge consistently across different populations and diagnostic instruments. The most dominant pattern is the belief that all hydrogen-containing compounds are acids, which reflects an overgeneralization of introductory textbook definitions and a lack of deeper conceptual understanding of acid–base theories.

This misconception has been supported by studies indicating that students often conflate various models of acid-base chemistry, including the Arrhenius, Brønsted–Lowry, and Lewis theories, leading to a lack of clarity in distinguishing between different types of acids and bases (Amalia et al., 2018; Crandell et al., 2018; Kampamba, 2023). Furthermore, investigations have shown that many students enter chemistry courses with misconceptions originating from prior educational experiences, where they fail to develop a nuanced understanding of acid–base concepts that move beyond rote memorization of definitions (Eilks et al., 2018; Mubarak & Yahdi, 2020). Additionally, studies underscore the need for pedagogical approaches that incorporate practical demonstrations and conceptual scaffolding to help students navigate these misconceptions. Utilizing laboratory exercises that connect molecular-level representations to symbolic representations has been found to be instrumental in reinforcing students' understanding of acid-base chemistry. Another prominent pattern is the assumption that ionic bonds represent interactions between molecules, indicating persistent confusion between intermolecular forces and intramolecular bonding. This misconception is particularly problematic because it underlies difficulties in related areas such as molecular polarity and intermolecular forces.

Likewise, misconceptions in stoichiometry, where students see it only as algorithmic calculations without understanding the mole concept, point to the limitations of traditional teaching approaches that emphasize procedures over concepts.Similarly, in buffer systems, students consistently demonstrate the misconception that buffers neutralize acids and bases completely. This pattern aligns with the high levels of misconceptions reported for buffer solutions in general, highlighting this topic as one of the most critical areas for instructional attention. Additional patterns are observed in equilibrium, where students believe that reactions stop once equilibrium is reached, and in redox reactions, where they often equate redox exclusively with changes in oxidation numbers. Taken together, the topic-specific findings and the recurring patterns identified in Figure 1 demonstrate that misconceptions in chemistry are both widespread and systematic. They are not isolated to individual topics but instead reflect deeper issues in how students conceptualize and connect fundamental chemical ideas. These results underscore the need for diagnostic assessments that capture both the content and the reasoning behind students' answers, as well as for teaching strategies that directly confront and remediate these deeply rooted misconceptions.

### *Distribution of Misconception Levels Across Chemistry Topics*

The distribution of misconception levels across chemistry topics, as illustrated in *Figure 2*, highlights the varying degrees to which students experience difficulties in mastering specific concepts. This distribution not only quantifies the extent of misconceptions but also allows for comparisons among topics, providing a clearer picture of which areas in chemistry learning require more urgent instructional interventions. The figure shows that the highest average levels of misconceptions occur in buffer solutions and hydrolysis, both exceeding 50%. These findings are consistent with the complex and abstract nature of these topics, which require students to integrate symbolic equations, microscopic particle behavior, and macroscopic phenomena. The high rates of misconceptions suggest that students often struggle to reconcile these levels of representation, leading to systematic misunderstandings that persist even after formal instruction.

Chemical bonding, electrolytes, and chemical equilibrium exhibit notably high levels of misconceptions, averaging between 44% and 50%. In chemical bonding, students often struggle with differentiating between ionic and covalent interactions, understanding polarity, and drawing Lewis structures accurately. Misconceptions surrounding ionic compounds as strong electrolytes often stem from oversimplified explanations in educational contexts Lewis (R. A. Sari & Yusmaita, 2023). Regarding chemical equilibrium, students commonly hold erroneous beliefs that reactions cease entirely at equilibrium or misinterpret Le Chatelier's principle, misunderstanding the dynamic nature of equilibria (Bernal-Ballén & Ospina, 2019; Golestaneh & Mousavi, 2024). Research indicates that the intrinsic complexity of these topics, combined with educators' challenges in effectively communicating these concepts, significantly contributes to persistent misunderstandings among students. While these topics may not be as problematic as buffer solutions, they still represent enduring conceptual challenges that educators must address to enhance students' learning experiences in chemistry (Andriani et al., 2021; Nahadi et al., 2018).

On the other hand, stoichiometry, thermochemistry, and redox reactions show relatively lower levels of misconceptions, averaging around 19–31%. While this indicates fewer overall misunderstandings, the persistence of certain patterns—such as treating stoichiometry purely as computational exercises, confusing heat with temperature in thermochemistry, or reducing redox solely to changes in oxidation numbers—demonstrates that even topics with lower average percentages are not free from conceptual difficulties. Overall, the distribution in *Figure 2* confirms that misconceptions are not evenly spread across the chemistry curriculum but instead cluster around topics that demand a higher degree of abstraction and integration of multiple representations. This reinforces the argument that instructional strategies must be differentiated: high-risk topics like buffer solutions and hydrolysis require more intensive conceptual scaffolding, while topics with lower misconception rates still need targeted interventions to address specific recurring errors.

### *Causes of Misconceptions*

The synthesis of the reviewed studies also reveals the underlying causes of misconceptions, as summarized in *Figure 3*. These causes can generally be grouped into three categories: student-related factors, teacher-related factors, and material-related factors. The distribution confirms that misconceptions are rarely the result of a single factor but rather stem from the interplay of prior knowledge, instructional practices, and the inherent complexity of chemistry itself. The most dominant cause is students' prior misconceptions, reported in approximately 70% of the reviewed studies. This indicates that learners often enter the classroom with pre-existing alternative conceptions derived from everyday experiences, informal knowledge, or earlier instruction. Because these ideas are deeply ingrained and often seem intuitively correct, they become resistant to change even when confronted with scientifically accurate explanations.

The second most frequently cited factor is the abstract nature of chemistry, reported in around 65% of studies. Chemistry requires learners to think across multiple representational levels—macroscopic, submicroscopic, and symbolic—which poses cognitive challenges. Concepts such as molecular interactions, equilibrium dynamics, or particle-level reasoning are inherently difficult to visualize, leading to persistent gaps in understanding. Material-related issues also play a significant role. Inaccurate or oversimplified textbooks (50%) and ambiguous chemical language (40%) frequently reinforce or create misconceptions. For example, phrases like "electron sharing" or "pure substance" may be interpreted differently by students than by chemists. These linguistic ambiguities create fertile ground for misunderstandings. From the instructional perspective, insufficient teacher explanation (45%) and overly algorithmic teaching methods (35%) contribute significantly.

In many cases, teaching emphasizes procedures and problem-solving algorithms rather than conceptual understanding. As a result, students may become proficient in calculations without building accurate mental models of underlying concepts. Finally, a smaller yet notable cause is peer and Internet influence (20%), where misconceptions spread informally among students or are reinforced by unreliable online sources. While less frequent than other causes, this highlights the importance of guiding students toward credible resources and fostering critical thinking in evaluating information. Taken together, the causes outlined in *Figure 3* demonstrate that misconceptions in chemistry are systemic and multifaceted. Addressing them requires a holistic approach that not only corrects errors in students' prior conceptions but also improves the clarity of instructional materials, enhances teachers' pedagogical strategies, and ensures that abstract concepts are taught with appropriate scaffolding and visualization.

## Conclusion

This systematic review analyzed thirty empirical studies published between 2015 and 2025 that investigated students' misconceptions in chemistry using various diagnostic instruments, including two- to five-tier tests and the Certainty of Response Index (CRI). The findings revealed that misconceptions are persistent and systemic across educational levels, particularly in buffer solutions, hydrolysis, and chemical bonding, followed by equilibrium, stoichiometry, and redox reactions. These misconceptions stem mainly from three sources: student-related factors (prior knowledge and abstract reasoning difficulties), teacher-related factors (algorithmic teaching and limited diagnostic awareness), and material-related factors (textbook inaccuracies). Such findings indicate that misconceptions are not isolated cognitive issues but part of broader pedagogical challenges that require systematic intervention.

Pedagogically, the review emphasizes integrating diagnostic assessments into chemistry instruction to uncover both incorrect responses and the reasoning behind them. Effective remediation should involve conceptual change strategies, cognitive conflict tasks, and multi-representational learning approaches that connect macroscopic phenomena with symbolic and molecular interpretations. Future research should focus on developing adaptive digital diagnostic tools with real-time feedback and conducting longitudinal studies to track the evolution of misconceptions and evaluate targeted teaching interventions. Although this review was limited to studies indexed in major databases and subject to possible publication bias, the use of established appraisal tools (JBI and MMAT) ensured methodological rigor and ethical compliance, offering a credible synthesis of misconceptions in chemistry education.

## Acknowledgment

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