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Mental Models and Conceptual Change in Chemistry: A Literature-Based Perspective on Learning Challenges

Zulqifli Alqadri[1], Munawwarah*[2]

[1]*Science Education Study Program, Universitas Negeri Makassar, Makassar, Indonesia*

[2]*Chemistry Education Study Program, Universitas Negeri Makassar, Makassar, Indonesia*

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* *Corresponding author:*

E-mail: munawwarah@unm.ac.id

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A B S T R A C T

This study aims to analyze students' mental models in chemistry, identify persistent misconceptions, and explore instructional strategies that facilitate conceptual change. A systematic literature review (SLR) approach was employed, examining 15 selected studies published between 2014 and 2024 from reputable academic sources. The findings reveal that synthetic models dominate students' understanding across various chemistry topics, indicating a mix of correct and incorrect scientific conceptions. Misconceptions are particularly prevalent in chemical equilibrium, redox reactions, and acid-base concepts, where students struggle to integrate macroscopic, submicroscopic, and symbolic representations. The study also reviews instructional strategies, including inquiry-based learning, model-based reasoning, and technology-enhanced approaches such as augmented reality (AR) and computer simulations. While these methods improve conceptual understanding, the transition from naive to scientific models remains challenging. The results highlight the need for interactive, multi-representational teaching methods to promote a more robust conceptual framework in chemistry learning. This review contributes to chemistry education by providing insights into effective pedagogical approaches for addressing misconceptions and improving students' conceptual development.

1. Introduction

Understanding chemistry concepts poses significant challenges for students, primarily due to the abstract and microscopic nature of various chemical phenomena. Research indicates that many students struggle to formulate scientifically accurate mental representations of critical concepts such as atomic structure and chemical bonding. These mental representations, often referred to as mental models, are crucial in shaping students' interpretations and problem-solving approaches in chemistry (Lahlali et al., 2023). Studies have demonstrated that students frequently hold mental models that are misaligned with established scientific explanations, which leads to persistent misconceptions that obstruct meaningful learning and hinder knowledge advancement (Kimberlin & Yezierski, 2016; Lahlali et al., 2023; Reina et al., 2022). In the context of chemistry education, mental models can be classified into three distinct categories: initial models, which represent students' preconceived, often naive conceptions; synthetic models, which exhibit a blend of correct and incorrect beliefs developed in response to instruction; and scientific models that conform to expert consensus.

An extensive analysis of literature reveals that synthetic models are predominant across various chemistry topics, indicating that significant conceptual changes frequently do not occur even after formal instruction (Kimberlin & Yezierski, 2016; Lahlali et al., 2023). Furthermore, this prevalence of synthetic models highlights the necessity for educators to pinpoint specific learning obstacles and to craft targeted instructional strategies that facilitate students' progression toward scientifically accurate understandings (Djarwo & Kafiar, 2023). One considerable challenge in promoting conceptual change within chemistry education is the entrenched nature of students' mental models.

Many students exhibit resistance to modifying their initial conceptions despite exposure to scientifically sound explanations, a phenomenon particularly noticeable in intricate subjects such as acid-base equilibria, redox reactions, and thermochemistry (Adu-Gyamfi & Asaki, 2022; Karini et al., 2022). These areas often elicit difficulty for learners as they try to reconcile observable phenomena with underlying theoretical frameworks, exacerbating misunderstandings and leading to fragmented learning experiences (Galloway & Bretz, 2015; Seyhan & Türk, 2022).

The prominence of synthetic models illustrates that students often assimilate new information without holistic restructuring of their conceptual frameworks, resulting in incomplete comprehension and ongoing misconceptions (Mubarak & Yahdi, 2020). To effectively encourage conceptual change, educational strategies must address these challenges through the implementation of instructional methods that actively engage students in model-based reasoning. Various innovative approaches, including inquiry-based learning, use of multiple representations, and cognitive conflict strategies, have shown promise in aiding students' transitions from naive or synthetic models to scientifically accepted ones (Cai, 2022; Holme et al., 2015).

Nevertheless, the effectiveness of these instructional strategies may fluctuate based on the complexity of the concepts, students' cognitive maturity, and the specific teaching context, necessitating a nuanced application of these methods to meet diverse learner needs (Gültepe, 2016; Reina et al., 2022).

Despite the extensive exploration of mental models within chemistry education, substantial gaps remain in understanding how students navigate transitions between different model types. Furthermore, the exploration of instructional interventions that facilitate these shifts warrants deeper investigation (Galloway & Bretz, 2015). The interplay of metacognition and self-regulation also emerges as an important area for future research, as these elements significantly influence students' abilities to engage in meaningful conceptual change (Djarwo & Kafiar, 2023; Seyhan & Türk, 2022). Addressing these research gaps is essential for refining chemistry curricula and enhancing pedagogical practices that support comprehensive learning experiences for students.

This study articulates a state-of-the-art review concerning the patterns, challenges, and educational implications of mental models in chemistry learning. By methodically analyzing existing literature, we aim to disclose trends in students' conceptual development, evaluate the effectiveness of various pedagogical strategies, and underscore vital factors that impact conceptual change (Gültepe, 2016; Jammeh et al., 2023). Such insights will provide rich guidance for educators, researchers, and curriculum developers striving to implement best practices that facilitate students' transitions toward scientifically accurate understandings of chemistry concepts.

The overall aim of this review is to provide an extensive analysis of mental models as they relate to chemistry education, particularly focusing on the challenges of learning and instructional strategies designed to instigate conceptual change. By synthesizing findings from previous studies, we hope to enrich the knowledge base and practical resources available to educators, facilitating improved outcomes in students' understanding of chemical principles (Gültepe, 2016).

2. Methodology

This study employs a systematic literature review (SLR) to analyze the patterns of students' mental models in understanding chemistry concepts, identify common misconceptions, and explore the educational implications based on previous research findings. The research follows the SLR model, focusing on the identification, selection, and critical analysis of relevant studies on mental models in chemistry. A qualitative descriptive approach is used in this study, where data is collected from published scholarly articles and analyzed to uncover students' mental model patterns, challenges in chemistry learning, and instructional strategies utilized in prior studies.

Article Selection Procedure

The article selection process was conducted in multiple stages:

a. Data Sources: Articles were retrieved from reputable international journals such as *Research in Science Education, Chemistry Education Research and Practice, Journal of Chemical Education*, and others.
b. Keywords: The search was performed using keywords such as *mental models in chemistry, misconceptions in chemistry education, students' understanding of chemistry concepts,* and *instructional strategies in chemistry learning.*
c. Inclusion Criteria:

1) Articles published within the last ten years (2014–2024) to ensure relevance to current research.
2) Articles that specifically discuss students' mental models in understanding chemistry concepts.
3) Articles that provide empirical analysis of misconceptions or students' understanding patterns.
4) Articles that highlight educational implications or instructional strategies to address misconceptions.

d. Exclusion Criteria:
1) Articles focusing solely on theoretical aspects without empirical data.
2) Studies not directly related to chemistry education.
3) Articles with restricted access that could not be fully analyzed.

Rationale for Selecting 15 Articles from an Initial 30

In the SLR process, a rigorous selection was conducted based on inclusion and exclusion criteria to ensure that the analyzed articles were highly relevant to the research objectives. Out of the initial 30 articles, only 15 were selected based on the following considerations:

1. The selected articles specifically address students' mental models in chemistry learning, including how they construct their understanding, common misconceptions, and the factors influencing different mental model patterns. Articles that only discuss general aspects of chemistry education without emphasizing mental models were excluded.
2. Only articles published in high-impact international journals or indexed national journals were selected. The sources include *Research in Science Education, Chemistry Education Research and Practice, Journal of Chemical Education*, and other credible academic journals. Articles from non-peer-reviewed sources or less reputable journals were excluded.
3. Publication Time frame (2014–2024). To ensure relevance to the latest developments in chemistry education, only articles published within the last ten years were considered. Older articles (pre-2014) were generally excluded unless they made significant theoretical contributions.
4. The selected articles contain empirical data supporting discussions on students' mental models. Conceptual or theoretical papers without empirical evidence were excluded, as they do not provide concrete insights into students' understanding patterns.
5. Diversity in Chemistry Topics. To ensure a comprehensive analysis, the selected articles cover various chemistry concepts. Articles explicitly addressing these topics were prioritized over those focusing on niche subjects with limited relevance to multiple studies.
6. Variety of Research Methods in Selected Studies. To obtain broader insights, the selected articles utilize various research methods, such as:
   a. Qualitative studies (interviews and analysis of students' understanding).
   b. Quantitative studies (statistical analysis of misconceptions and mental model patterns).

c. Experimental studies (intervention-based research to modify students' mental models).
d. Mixed-method studies (combining interviews, diagnostic tests, and observations).

Articles that used only a single method without providing a deeper understanding of students' mental models were excluded.

7. Clear Educational Implications. Only articles with direct educational implications were selected. Studies that do not offer concrete recommendations on how to modify or enhance students' mental models in chemistry learning were excluded from the final selection.

Data Analysis Techniques

The analysis follows a content analysis approach, where selected articles are categorized based on key aspects:

1. Chemistry Concepts Studied; Identifying the chemistry topics that the research focuses on.
2. Students' Mental Model Patterns; Analyzing how students conceptualize chemistry concepts and the misconceptions that arise.
3. Instructional Strategies Used; Evaluating teaching approaches or methods suggested in each study.
4. Educational Implications; Summarizing key findings to provide recommendations for improving chemistry education effectiveness.

3. Result and Discussion

Overview of Research on Students' Mental Models in Chemistry

Understanding students' mental models in chemistry is crucial for identifying misconceptions and improving instructional strategies. Numerous studies have explored how students conceptualize various chemistry topics, the challenges they face in transitioning to scientific models, and the effectiveness of different teaching approaches. Table 1 summarizes key findings from selected studies on students' mental models in chemistry, highlighting their research focus, methods, main findings, and educational implications.

Table 1. Review of Selected Studies on Students' Mental Models in Chemistry

No	Authors & Year	Research Focus	Research Method	Key Findings	Educational Implications
1	(Lin et al., 2014)	Students' mental models and misconceptions in acid-base concepts	Qualitative study with pre- and post-instruction interviews and two-tier diagnostic tests	High-achieving students tend to develop scientific models after formal instruction, while low-achieving students remain influenced by everyday experiences	Teachers need to differentiate between character-symbol models and scientific models to prevent further misconceptions.

No	Authors & Year	Research Focus	Research Method	Key Findings	Educational Implications
				and intuition.	
2	(Albaiti et al., 2016))	Mental models in the binary system of n-hexane and methanol	Experimental method using the cloud point method	Students' mental models were formed within four curve areas representing molecular interactions between n-hexane and methanol.	Visualization of submicroscopic representations in laboratory experiments can help students better understand chemical phenomena.
3	(Majid, 2018)	Misconceptions in atomic structure based on mental models	Qualitative analysis using students' perception and comprehension tests	Misconceptions are more prevalent among students with initial mental models, while students with more advanced models show fewer misconceptions.	Aligning students' mental models before teaching atomic structure is crucial to preventing misconceptions.
4	(Redhana et al., 2020)	Students' mental models on acid-base topics	Survey with 279 high school students	35.56% had initial mental models, 61.76% had synthetic models, and 2.69% had scientific models.	Teaching strategies should incorporate multiple representations to reduce misconceptions in acid-base topics.
5	(Suja et al., 2020)	Pre-service teachers' mental models on organic compound structures and properties	Two-tier test with 22 students	Only 1.36% had conceptual models before instruction, increasing to 62.73% after using the TripleChem learning model.	The TripleChem learning model is effective in developing conceptual mental models of organic chemistry.
6	(Sinaga, 2022)	Mental models of pre-service chemistry teachers on chemical equilibrium	Descriptive study using diagnostic tests on 22 students	Variations in understanding across macroscopic, submicroscopic, and symbolic representations, with submicroscopic comprehension being the weakest.	Instructional strategies should integrate multiple representations to enhance students' understanding of submicroscopic concepts.
7	(Praisri & Faikhamta, 2020)	Developing students' mental models of chemical equilibrium through argumentation in model-based learning	Qualitative study using classroom observations, teacher logs, and student reflections	Argumentation in model-based learning helps students develop scientific mental models, especially in understanding dynamic equilibrium and reversible reactions.	Model-based learning should emphasize argumentation to improve students' conceptual understanding.
8	(Umayah et al., 2023)	Students' mental models in salt hydrolysis using	Descriptive qualitative study with classroom	7.20% had initial models, 53.90% had synthetic models, and	Augmented reality-based learning can enhance students'

No	Authors & Year	Research Focus	Research Method	Key Findings	Educational Implications
		augmented reality	observations, interviews, and final tests	38.90% had scientific models; AR significantly improved students' submicroscopic representation skills.	spatial ability in understanding chemical concepts.
9	(Murni et al., 2022)	Effects of structured inquiry-based reaction rate modules on students' mental models	Experimental study with control and experimental groups	Students using structured inquiry-based modules had significantly higher mental model development and learning outcomes than the control group.	Integrating three levels of chemical representation in structured inquiry-based modules enhances conceptual understanding.
10	(Thacker & Sinatra, 2019)	Visualization of the greenhouse effect and restructuring of mental models in climate change education	Design-based study using interviews and online simulations	Most students initially had misconceptions about climate change, but their understanding improved after interactive simulations.	Interactive visual-based simulations can help students develop more accurate scientific mental models.
11	(Derkach, 2021)	Misconceptions in inorganic chemistry and computer-based modeling	Case study with 461 secondary school students using computer simulations	Students often misunderstand the relationships between microscopic, macroscopic, and symbolic representations.	Computer simulations can help correct misconceptions and enhance conceptual understanding in chemistry.
12	(Latipah et al., 2021)	Mental models in chemistry through augmented reality	Literature review and qualitative-quantitative approach	Augmented reality improves students' comprehension of chemical representations.	AR-enhanced textbooks can improve students' mental models in chemistry learning.
13	(Bilir & Karaçam, 2021)	Pre-service science teachers' mental models on chemical reactions	Interviews and diagram-based tests with 48 pre-service teachers	Most students use a particle model to represent chemical reactions, with transitions to atomic models occurring at higher education levels.	Visual representations based on atomic models should be emphasized in chemistry instruction.
14	(Albaiti et al., 2016)	Validation of physical chemistry laboratory procedures using mental models	Experimental method using laboratory observations	Students' mental models of the n-hexane-methanol binary system evolved from macroscopic to submicroscopic representations.	Laboratory-based molecular modeling can bridge macroscopic observations with submicroscopic understanding.
15	(Derkach, 2021)	Correcting misconceptions in	Case study with 461 secondary	Misconceptions in inorganic chemistry	Computer simulations

No	Authors & Year	Research Focus	Research Method	Key Findings	Educational Implications
		inorganic chemistry through interactive computer modeling	school students	can be corrected through interactive computer-based models.	effectively enhance students' understanding of abstract chemistry concepts.

The analysis of students' mental models in chemistry highlights a recurring pattern of misconceptions and incomplete conceptual understanding across various topics. The reviewed studies show that students often struggle to transition from initial mental models, which are based on everyday experiences, to scientific mental models that align with expert knowledge. In most cases, students remain in the synthetic model stage, where they integrate some correct scientific concepts but still hold onto intuitive misconceptions.

This is particularly evident in topics such as acid-base reactions, chemical equilibrium, and redox reactions. Lin et al. (2004) found that students often misinterpret neutralization as always producing a completely neutral solution and fail to grasp the logarithmic nature of the pH scale. Similarly, Redhana et al., (2020) that only 2.69% of students had a fully developed scientific model of acid-base reactions, emphasizing the persistence of fragmented and inconsistent conceptual understanding.

One of the most significant challenges in chemistry education is students' difficulty in integrating macroscopic, submicroscopic, and symbolic representations. Albaiti et al. (2016), Sinaga (2022) highlight that many students fail to link observable chemical reactions with their atomic and molecular underpinnings, resulting in an incomplete understanding of equilibrium dynamics. A common misconception is that chemical equilibrium is a static state, rather than a dynamic process involving continuous forward and reverse reactions.

This misunderstanding can be exacerbated by the way traditional chemistry textbooks present equilibrium concepts, often focusing on symbolic equations without emphasizing the particulate nature of the reaction. Praisri & Faikhamta (2020) suggest that Argumentation within Model-Based Learning (AMBL) can help address this issue by encouraging students to construct, test, and refine their mental models through structured discussions and evidence-based reasoning. Their study found that AMBL improved students' ability to articulate their reasoning and modify incorrect representations, making it a promising pedagogical approach for fostering deeper conceptual understanding.

Another key finding from the reviewed literature is the impact of instructional strategies on students' mental model development. Latipah et al. (2021), Murni et al. (2022), Umayah et al. (2023) explored structured inquiry-based learning, augmented reality (AR), and computer simulations as tools for enhancing conceptual understanding. Their studies indicate that interactive, multi-representational approaches significantly improve students' ability to visualize and conceptualize abstract chemical processes. For example, AR-based learning was found to enhance spatial reasoning and submicroscopic visualization, particularly in complex topics such as chemical bonding and reaction mechanisms. Furthermore, structured inquiry-based learning encouraged students to engage in hypothesis-driven reasoning, reinforcing their ability to connect symbolic equations with real-world chemical behaviors. These findings suggest that chemistry instruction should move beyond passive learning approaches and incorporate active, technology-enhanced, and inquiry-driven methodologies to facilitate meaningful conceptual change.

Despite these promising strategies, several studies highlight persistent challenges in shifting students from synthetic to fully scientific models. Derkach (2021) found that even after using computer-based simulations, some students retained misconceptions about inorganic chemistry, particularly regarding the nature of ionic and covalent bonding. Similarly, Thacker & Sinatra (2019) noted that while visual simulations improved students' understanding of environmental chemistry, their mental model restructuring required continuous reinforcement and iterative learning experiences.

This underscores the need for long-term instructional interventions that systematically challenge misconceptions rather than relying on single-exposure activities. Additionally, gender differences in conceptual understanding, as reported by Redhana et al. (2020), suggest that personalized instructional approaches may be necessary to accommodate different learning preferences and strengths.

Comparison of Students' Mental Models in Chemistry

Students' understanding of chemistry concepts evolves through different stages, from naive misconceptions to scientifically accurate mental models. This progression is often categorized into Initial Mental Models, where students rely on everyday intuition, Synthetic Mental Models, where partial scientific understanding is mixed with misconceptions, and Scientific Mental Models, where students develop a conceptually accurate understanding. Table 2 provides a comparative analysis of students' mental models across various chemistry topics, highlighting common misconceptions and the transition toward scientific reasoning.

The analysis of students' mental models in chemistry reveals a consistent pattern of misconceptions across various topics. Many students begin with initial mental models influenced by everyday experiences and intuitive reasoning. For instance, in acid-base chemistry, students often maintain the misconception that all acids are hazardous while considering bases to be safe. Additionally, in the topic of chemical equilibrium, there is a prevalent misunderstanding that reactions only progress in one direction and cease when equilibrium is achieved, can be seen in Table 2.

Table 2. Comparison of Mental Models in Various Chemistry Topics

No	Chemistry Topic	Initial Mental Model	Synthetic Mental Model	Scientific Mental Model
1	**Acid-Base**	Believes acids are "dangerous" substances and bases are "non-toxic".	Recognizes the concept of H^+ and OH^- ions but assumes that mixing acids and bases always results in a neutral solution.	Understands the Arrhenius, Brønsted-Lowry, and Lewis acid-base theories and ionization mechanisms.
2	**Chemical Equilibrium**	Assumes reactions proceed in only one direction and stop once equilibrium is reached.	Understands that reactions are reversible but incorrectly believes that the concentration of substances remains unchanged.	Comprehends equilibrium as a dynamic state where the forward and reverse reaction rates are equal.
3	**Redox Reactions**	Thinks redox reactions only occur when there is a color change or rust formation.	Recognizes oxidation and reduction processes but struggles to understand electron transfer.	Understands oxidation numbers, electrochemical cells, and the relationship between oxidizing and reducing agents.
4	**Atomic Structure**	Views the atom as an indivisible small sphere.	Acknowledges electrons but perceives their orbits as planetary-like.	Understands the quantum mechanical model, including probabilistic orbitals.
5	**Chemical Bonding**	Assumes atoms "stick" together without any specific attractive forces.	Recognizes ionic and covalent bonding but believes covalent bonds always share electrons equally.	Understands electronegativity, hybridization, and intermolecular interactions.
6	**Thermochemistry**	Considers heat as a tangible substance that can be transferred physically.	Recognizes that reactions can be exothermic or endothermic but lacks understanding of enthalpy change.	Understands Hess's Law, bond energy, and energy transfer in thermodynamic systems.
7	**Reaction Rate**	Thinks reaction rate depends only on the amount of reactants mixed.	Understands that temperature and concentration influence reaction rates but struggles to explain the collision mechanism.	Comprehends the collision theory and activation energy in chemical processes.
8	**Salt Hydrolysis**	Assumes all salts are neutral in aqueous solutions.	Recognizes that some salts are acidic or basic but struggles to explain why.	Understands salt hydrolysis based on Brønsted-Lowry acid-base theory and ion equilibrium.

Such intuitive models highlight a fundamental lack of understanding regarding the principles that govern chemical reactions at the submicroscopic level, thereby indicating the need for pedagogical interventions to facilitate conceptual development (Taber, 2013; Tümay, 2016; Wardah & Wiyarsi, 2020). Moreover, teachers play a crucial role in guiding mental model development to ensure that students do not form unscientific mental models, underscoring the importance of structured instructional approaches (Wardah & Wiyarsi, 2020).

As students progress through formal education, they often form synthetic mental models that incorporate some scientific concepts while retaining existing misconceptions. This trend is particularly evident in the study of redox reactions, where students may grasp the paired nature of oxidation and reduction but struggle to understand the electron transfer process at the atomic level. Similarly, in chemical bonding, students recognize that atoms form bonds but may incorrectly assume that covalent bonds involve an equal sharing of electrons.

Challenges also arise in thermochemistry, where students identify exothermic and endothermic reactions but often fail to understand the nuances of enthalpy changes and energy mechanisms involved in these processes (Getu et al., 2024; Taber, 2013). These observations suggest that traditional instructional methods may inadequately support the transition from fragmented understanding to a more cohesive scientific framework, necessitating innovative pedagogical strategies that focus on multi-level representations (DeKorver et al., 2020; Han, 2024).

To effectively foster the development of scientific mental models, educational strategies must integrate macroscopic, submicroscopic, and symbolic representations in chemistry instruction. For example, in discussing reaction rates, initial student beliefs often center on the quantity of reactants mixed, but effective instruction can shift their understanding to include collision theory and activation energy concepts. Similarly, in the case of salt hydrolysis, misconceptions such as assuming all salts are neutral can be rectified through structured learning experiences that convey the role of ion equilibrium in determining solution pH.

Empirical evidence supports the idea that inquiry-based learning, model-based reasoning, and interactive simulations can significantly enhance students' conceptual understanding, enabling a complete transition to scientific mental models (Abdel-Halim, 2020; Amalia et al., 2018; Hidayati et al., 2018). Thus, employing these techniques is crucial for reshaping students' perceptions in alignment with scientific principles.

Figure 1 provides a visual representation of students' mental models across various chemistry topics, complementing the data previously presented in the table. It categorizes students' understanding into Initial Model, Synthetic Model, and Scientific Model, illustrating the distribution of misconceptions, transitional thinking, and scientifically accurate conceptions. Figure 1 highlights the prevalence of synthetic models, indicating that while students incorporate some scientific ideas, they often retain misconceptions. The relatively low percentage of students achieving a scientific model suggests that many struggle to fully internalize accurate chemical concepts. By analyzing this graph, we can further explore the challenges students face in conceptualizing chemistry topics and discuss the implications for instructional strategies.

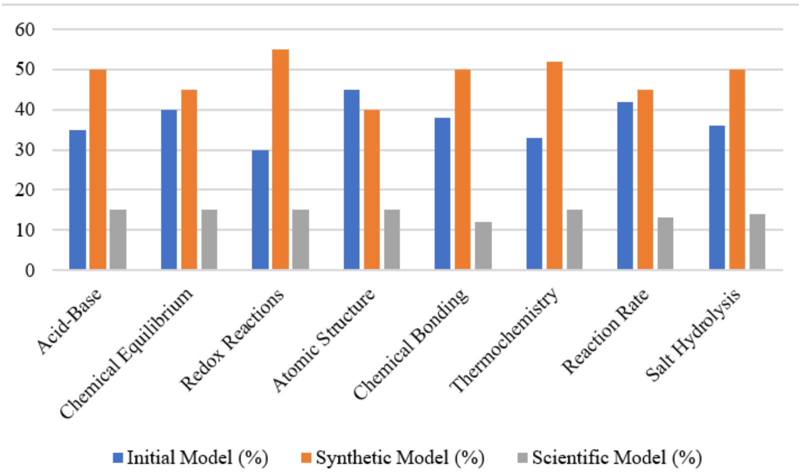

Figure 1. Distribution of Students' Mental Models Across Various Chemistry Topics

Figure 1 reveals that across all chemistry topics, the Synthetic Model dominates, indicating that most students exhibit a mix of scientific understanding and misconceptions. This pattern is particularly evident in Redox Reactions, Thermochemistry, and Salt Hydrolysis, where over 50% of students hold synthetic mental models. This suggests that while students grasp certain scientific principles, they still struggle with conceptual clarity, leading to fragmented or incorrect interpretations. Meanwhile, the Initial Model remains significant, especially in Chemical Bonding and Atomic Structure, implying that a considerable proportion of students rely on their pre-existing, often incorrect, intuitive reasoning rather than scientifically accurate explanations. The Scientific Model, representing a fully correct understanding, consistently appears as the least common across all topics, emphasizing the persistent challenge of achieving conceptual mastery in chemistry.

These findings highlight key instructional challenges in chemistry education. The predominance of synthetic and initial models suggests that traditional teaching methods may not effectively facilitate conceptual change, as students often integrate new knowledge inconsistently with their prior beliefs. To address this, educators should implement targeted interventions, such as inquiry-based learning, concept mapping, and real-world problem-solving approaches, to reinforce correct scientific models. Additionally, frequent diagnostic assessments can help identify and correct misconceptions early, fostering a gradual shift toward a deeper, more accurate understanding of chemistry concepts.

4. Conclusion

This study systematically analyzed students' mental models in understanding various chemistry concepts, highlighting prevalent misconceptions and their implications for chemistry education. The findings indicate that synthetic models dominate students' conceptualization across different topics, with a relatively low adoption of scientific models. This suggests that while students attempt to integrate scientific knowledge, their understanding often remains fragmented or influenced by prior misconceptions. Moreover, the persistence of initial models in complex topics such as chemical equilibrium and redox reactions underscores the challenges students face in conceptual change. These findings emphasize the need for instructional strategies that actively promote conceptual restructuring rather than mere memorization. The educational implications point to the importance of employing inquiry-based learning, conceptual conflict strategies, and model-based reasoning to facilitate a deeper and more accurate understanding of chemistry concepts. Ultimately, this research underscores the necessity of refining chemistry curricula and teaching methodologies to bridge the gap between students' mental models and scientifically accepted frameworks. Future studies should explore the effectiveness of different pedagogical interventions in shifting students' mental models toward a more scientifically accurate understanding.

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