Conceptual Change for Improving Chemistry Education in Ethiopia: A Conceptual Literature Review

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Abstract:

Research on conceptual change (CC) has demonstrated that students often struggle when learning involves substantial modifications to their existing knowledge. Despite the extensive and sophisticated discourse surrounding CC theories and strategies in science education, a notable failure persists in translating these well-researched frameworks into substantive conceptual understanding among learners. Numerous studies indicate that conventional teaching methods are inadequate to support these cognitive shifts. Drawing on a conceptual literature review, this article presents a comprehensive examination of the foundations of CC, CC theory, and its application within science and chemistry education. The discussion spans the meaning of CC, theoretical frameworks, instructional strategies like conceptual change texts, analogies, and demonstrations, and limitations of conventional instructional approaches. It highlights empirical research evidencing improved learning outcomes through CC approaches. The article uncovers the complexities and best practices for facilitating CC in chemistry, aiming to enhance both teaching methods and student comprehension in chemistry. This review has led to a set of informed conclusions and actionable recommendations.

Keywords: *Conceptual change, Cognitive conflict, Concept cartoons, Chemistry education*

1. Introduction

Chemistry is widely regarded as a challenging subject (Tutorition, 2025). More than 52% of high school students surveyed by the American Chemical Society ranked chemistry as the hardest science subject, even above biology and physics (Tutorition, 2025). Only a small percentage of students achieve the highest grades in chemistry compared to other subjects, as it demands a unique blend of abstract reasoning, memorization, and experimental interpretation (ChemTribe, n.d). In 2022, only **13.6%** of A-Level Chemistry students in England achieved an A*, compared to **22.8%** in Mathematics and **16.4%** in Physics, highlighting chemistry's relative grading difficulty (Department for Education, 2022). Based on official data from Cambridge International, the grade thresholds and results statistics confirm that fewer students achieve top grades in Chemistry compared to Mathematics and Physics across many exam series, including those taken in African countries. In particular, in 2025, grade thresholds for Chemistry are often set lower than those for Mathematics, reflecting the subject's relative difficulty and the lower proportion of candidates achieving top marks (Cambridge International, 2025). Despite the extensive discourse surrounding conceptual change (CC) theories and strategies in science education, many efforts fall short of fostering genuine conceptual understanding among learners due to a persistent gap between theory and practice. Researchers often emphasize diagnosing misconceptions or modeling mental processes without translating these insights into accessible, classroom-ready strategies—instruction that promotes CC with understanding matters in solving problems of the sort indicated here. For instance, a study indicated that inquiry-based instruction and problem-solving approaches significantly improve students' understanding and retention in chemistry, especially when adapted to local contexts (Sibomana et al., 2021). Another review work indicated that the use of improvised materials offers a cost-effective alternative to standard laboratory materials, promoting deeper learning and motivation in chemistry (Berhe et al., 2024). Moreover, innovative approaches such as inductive, Socratic, and student-centered methods are essential for improving chemistry instruction in classrooms (Ngendabanga et al., 2025). Yet misconceptions or understanding problems in chemistry remain prevalent due to persistent reliance on the conventional approach used (Sibomana et al., 2021). This review gives attention to CC literature and approaches associated with CC.

2. Objectives

This conceptual review aims to illuminate innovative instructional practices grounded in conceptual change (CC) approaches, particularly within the domain of chemistry education. The specific objectives are to:

- explore how Conceptual Change (CC) is defined and how its theoretical frameworks inform innovative pedagogical strategies in science education.
- examine the application of CC approaches in enhancing teaching and learning within chemistry classrooms.
- identify and synthesize instructional practices that promote meaningful conceptual restructuring among learners.

3. Methodology

3.1. Conceptual Orientation

This study employs a conceptual review methodology (Heinonen & Gruen, 2024) to conduct a wider exploration of conceptual change (CC) as a transformative lens for enhancing instructional practices in chemistry education. Rather merely summarizing empirical findings, a conceptual literature review constructs a semantic network of ideas, elucidates relationships among theoretical perspectives, and identifies enduring gaps in scholarly understanding (Heinonen & Gruen, 2024). Such papers/reviews are particularly valuable in domains characterized by theoretical diversity or where empirical consensus remains emerging. This conceptual review adopts a deeply reflective stance, prioritizing interpretive depth over rigid methodological constraints. Conceptual review embraces a flexible and critical engagement with literature. As Ayala (2018) argues, conceptual reviews are distinguished by their emphasis on interpretation, theoretical synthesis, and intellectual openness. In such endeavors, conceptual scholarship demands rigorous argumentation and a robust theoretical foundation. Its intellectual merit hinges not only on the originality of thought but also on the coherence, depth, and scholarly articulation of the concepts advanced. Conceptual reviews trace the evolution, refinement, and interrelation of theoretical constructs, thereby illuminating the intellectual architecture of a field. For this study, conceptual review is best suited for this work, as it maps the emergence, divergence, and convergence of ideas over time (Webster & Watson, 2002).

3.2. Literature Selection Criteria

The review draws upon both seminal (Kuhn, 1962; Posner et al., 1982) and contemporary literature (Potvin & Bélanger, 2024) within the domain of CC theory, with particular emphasis on its pedagogical implications for chemistry education. Sources were carefully selected based on their theoretical importance, disciplinary relevance, and publication status in peer-reviewed academic journals. Priority was given to works that substantively contributed to discourses on epistemological development, cognitive restructuring, and culturally responsive pedagogy.

3.3. Steps involved

3.3.1. Identifying the Central Concept

Identifying the central concept or phenomenon is the foundational step in conducting a conceptual literature review. It required selecting a topic that is both theoretically rich and contextually relevant to the field of inquiry. The chosen concept (Conceptual change) was broad enough to accommodate diverse theoretical perspectives yet sufficiently focused to provide a coherent analytical path. This clarity enabled the reviewer to trace conceptual developments, interrogate underlying assumptions, and synthesize theoretical contributions meaningfully. As Torraco (2005) underscores, a conceptual review must begin with a well-defined phenomenon or concept that justifies theoretical synthesis and invites intellectual exploration.

3.3.2. Conducting a Broad and Inclusive Literature Search

Conducting a broad literature search is essential for a robust conceptual review. This process involved exploring academic databases (Scopus, ERIC, and Google Scholar) to identify sources that examined the central concept (conceptual change) from diverse theoretical vantage points. Unlike systematic reviews, which adhere to rigid methodological criteria, conceptual reviews embrace flexibility in source selection, incorporating theoretical articles, book chapters, and policy documents that enrich the conceptual landscape. As Snyder (2019) emphasizes, the guiding principle in conceptual reviews is theoretical relevance rather than methodological uniformity, allowing for a more expansive synthesis of ideas. This approach enables a more expansive and interpretive synthesis of ideas, allowing scholars to engage critically with diverse sources and frameworks. Accordingly, the literature search in this review was guided by conceptual significance and thematic resonance, rather than by rigid inclusion criteria or indexing protocols.

3.3.3. Organizing the Literature Thematically

Organizing literature thematically or chronologically is a critical step in conceptual review methodology, as it enables the researcher to trace the intellectual evolution of a concept with clarity and coherence. Grouping sources by themes, schools of thought, or historical progression reveals how theoretical constructs have developed over time, where scholarly debates persist, and which frameworks have gained prominence. This structured synthesis not only highlighted converging and diverging perspectives but also exposed conceptual gaps that warrant further inquiry. As Webster and Watson (2002) advocate, thematic organization is particularly effective in uncovering patterns and deficiencies in conceptual understanding, thereby enriching the analytical depth of the review. Through clustering insights around emergent themes rather than chronologies or methodologies, this approach deepens interpretive clarity and enhances the conceptual coherence of the review. Accordingly, the present review adopted a thematic framework to structure its analysis, allowing for a synthesis of ideas related to conceptual change and instructional practices in chemistry education.

3.3.4. Critically Analyzing and Synthesizing Theoretical Perspectives

Critically analyzing and synthesizing theoretical perspectives is the intellectual core of a conceptual literature review. This step moved the reviewer beyond descriptive summary to engage with the literature interpretively comparing definitions, models, and underlying assumptions across sources. It involved identifying contradictions, overlaps, and areas of conceptual ambiguity, thereby revealing tensions and convergences within the CC literature. Through this process, the reviewer constructed a clear understanding of the CC concept's theoretical landscape. As Torraco (2005) emphasizes, synthesis is not merely additive; it is generative, enabling scholars to advance theory by integrating disparate strands of thought into a coherent and enriched framework. This review adopted such an integrative approach, aiming to construct a nuanced perspective on conceptual change and its implications for instructional practice in chemistry education.

3.3.5. Developing a Conceptual Framework

Developing a conceptual framework is the terminating step in a conceptual literature review, translating interpretive synthesis into a structured representation of interrelated ideas. This framework serves as a visual and intellectual map, illustrating how key concepts connect, influence, and inform one another within the theoretical landscape. It should reflect the touches uncovered during analysis—highlighting foundational constructs, mediating variables, and contextual factors—and offer a coherent guide for future research, policy formulation, or pedagogical practice. As Jabareen (2009) articulates, conceptual frameworks emerge from interpretive synthesis and function as dynamic tools for theorizing complex phenomena, enabling scholars to scaffold inquiry and advance disciplinary understanding. This review translated interpretive synthesis into a coherent and structured representation of interrelated concepts, enabling the articulation of theoretical linkages that illuminate patterns and pedagogical implications within the literature on conceptual change.

3.3.6. Reflecting on Gaps and Future Directions

Reflecting on gaps and future directions is a vital concluding step in a conceptual literature review, as it transforms synthesis into a springboard for scholarly advancement. In this review, this step involved identifying unresolved theoretical tensions, underexplored dimensions, and blind spots that persist across the literature. Through articulating these areas of ambiguity or neglect, the reviewer not only clarified the boundaries of current understanding but also signaled where future inquiry might be most fruitful. Such reflection positions the review as a generative platform—one that invites continued dialogue, challenges prevailing assumptions, and proposes new trajectories for research, policy, or practice. As Snyder (2019) affirms, conceptual reviews should not merely consolidate knowledge but actively stimulate intellectual discourse and shape future research agendas.

3.4. Analytical Procedures

A thematic synthesis approach guided the analytical process (as discussed in section 3.3.3above), enabling a structured yet interpretive engagement with the literature. This method facilitated the identification and categorization of recurring constructs, theoretical tensions, and paradigmatic shifts across diverse sources. Through conceptual clustering, the review traced how core ideas surrounding conceptual change (CC) theory have evolved, intersected, and diverged over time. Emphasis was placed on mapping the trajectory of CC theory within the broader science education discourse, with a focus on its uptake, adaptation, and critique in chemistry education. This contextual anchoring has contributed towards a better understanding of how CC theory has been used to address domain-specific challenges, revealing both its explanatory power and its limitations. The synthesis thus not only illuminated the intellectual architecture of CC theory but also positioned the review to contribute meaningfully to ongoing theoretical refinement and pedagogical innovation in the field.

3.5. Researcher Positionality

As Holmes (2020) argues, researcher positionality is not a limitation but a lens through which a deeper understanding can be gained, especially in qualitative and conceptual inquiries. Similarly, Zembylas (2025) advocates for reframing positionality statements as acts of solidarity and reflexive engagement, rather than mere declarations of identity. The synthesis presented in this review is deeply informed by the author's interpretive lens, cultivated through more than three decades of sustained professional engagement in chemistry instruction, curriculum development, and teacher education. This extensive experience has not only shaped the author's epistemological orientation but also provided a rich reservoir of pedagogical insight and disciplinary familiarity. Such a background enabled the reviewer to approach the literature with a practice-informed sensibility—attuned to both the theoretical underpinnings and the pragmatic realities of science education. This positionality enriched the conceptual analysis by grounding abstract constructs in lived instructional contexts, allowing for a more meaningful interpretation of how CC theory operates within the specific contours of chemistry education. Rather than striving for detached neutrality, the review embraced this standpoint as a source of analytical depth, reflexivity, and contextual authenticity.

4. Review of Related Literature

4.1. Foundations, Definitions, and Role of Conceptual Change in Chemistry Learning

Conceptual change (CC) is conceived by and an offspring of cognitive psychology (Gorodetsky & Keiny, 2002). It was introduced by Thomas Kuhn (1962) to designate that the concepts well-established in a scientific theory change their meaning when the paradigm changes. The meaning of CC has changed since its inception, and it is an evolving arena even today. Clement (2008) describes a range of types of CC like modifying an existing model by adding, removing, or changing elements; creating a new model; or replacing a concept with an ontologically different concept. Also, Mayer views it as the means underlying meaningful learning (Mayer, 2002). CC is a learning process in which students' alternative conceptions change or develop into the intended scientific conceptions (Vosniadou, 2007). It is an outgrowth of constructivist epistemology in which knowledge acquisition is viewed as a constructive process that involves actively generating and testing alternative propositions (Tyson et al., 1997). CC is all about the process by which learners restructure existing knowledge frameworks in response to new, conflicting information—often modifying or replacing naïve or intuitive understandings with scientifically accurate conceptions. Rooted in the work of Posner et al. (1982), CC theory posits four conditions for meaningful learning: dissatisfaction with prior conceptions, intelligibility, plausibility, and fruitfulness of the new concept. While early models emphasized cognitive conflict and individual mental restructuring, contemporary views—especially sociocultural and metacognitive perspectives—highlight the role of discourse, identity, and context in shaping conceptual development. In chemistry education, this shift is particularly relevant, as students often struggle with abstract representations and symbolic reasoning that challenge their everyday experiences (Alqadri & Munawwarah, 2025). Recent studies, such as Pacaci et al. (2024), validate the effectiveness of strategies like cognitive conflict and ontological shiftswhile Potvin and Bélanger (2024) advocate for representational pluralism in science communication. Nehm and Kampourakis (2016) further highlight the parallels between students' conceptual development and historical scientific revolutions, reinforcing the relevance of CC in chemistry instruction and curriculum reform.

Studies highlight the pivotal role of CC in fostering deep learning in chemistry, especially in topics like chemical equilibrium, redox reactions, and quantitative stoichiometry. Alqadri and Munawwarah (2025) conducted a systematic literature review analyzing students' mental models and persistent misconceptions, revealing that synthetic models—blending correct and incorrect conceptions—dominate learners' understanding. Instructional strategies such as inquiry-based learning, model-based reasoning, and augmented reality have shown promise in promoting CC by engaging students in multi-representational thinking. Similarly, Ginyigazi et al. (2024) demonstrated that a well-structured CC approach significantly improved learners' grasp of quantitative chemistry concepts, suggesting that targeted interventions can bridge the gap between surface-level memorization and deep conceptual understanding. These findings affirm the necessity of integrating CC frameworks into curriculum design and teacher education to enhance scientific literacy and critical thinking. Conceptual change (CC) research in science education has evolved from early "cold" cognitive models—focused on rational, conflict-driven thinking—to more comprehensive "hot" models that incorporate affective, motivational, and social dimensions. These approaches recognize that revising deeply held misconceptions involves not only intellectual dissatisfaction and plausibility judgments but also emotions, epistemic beliefs, motivation, and collaborative argumentation. Practical interventions and meta-analyses have strengthened the understanding of effective strategies for fostering CC. Moreover, the field increasingly applies CC research beyond classroom science learning to areas like public understanding of science and digital education contexts (Dole & Sinatra, 1998; Kural & Kocakülah, 2016; Hewson et al., 1998; Sinatra & Pintrich, 2003; Vosniadou, 2013).

The early CC theory, inspired by Thomas Kuhn's paradigm shifts, began with cognitive conflict models that emphasized dissatisfaction with prior knowledge and the logical assimilation of new, scientifically accurate ideas. Posner et al. (1982) proposed such a cognitive model that dominated early research and practice. However, by the 1990s and 2000s, researchers introduced affective and motivational factors leading to "hot" CC models. These include students' emotions (anxiety, confidence), epistemic cognition (beliefs about knowledge and knowing), and social interaction, particularly through collaborative argumentation and discourse. The "Teaching Model for Hot CC" highlights motivation and metacognitive strategies alongside cognitive conflict to create a more holistic CC experience (Kural & Kocakülah, 2016; Pintrich et al., 1993).

Contemporary CC research emphasizes instructional strategies that actively engage students' existing misconceptions while supporting new scientific conceptual understanding. Techniques include cognitive conflict induction, cognitive bridging, and ontological category shifts, allowing students to rethink their conceptual categories (Chi, 2008; Vosniadou, 2013; Limón, 2001). Effective interventions foster motivation, provide multiple representations, allow students to test and reflect on ideas, and promote collaborative argumentation. Meta-analyses validate that such strategies significantly enhance science learning outcomes (Pacaci et al., 2024).

Through time, CC research in science education has transitioned from cold, purely cognitive accounts to integrative hot models incorporating affective and social factors, underpinned by practical and empirically supported teaching strategies and expanding into wider educational and societal domains (Hewson et al., 1998; Kural & Kocakülah, 2016; Pintrich et al., 1993; Vosniadou, 2013). As chemistry is full of abstract, counterintuitive ideas (atoms, molecules, reactions, equilibrium, etc.) that often clash with students' everyday experiences, CC approaches are foundational to meaningful chemistry learning (Alqadri & Munawwarah, 2025).

4.2. Theoretical Frameworks of Conceptual Change to Enhance Learning

Conceptual change stands for the cognitive process by which learners transition from a state of misunderstanding or incomplete understanding to a more accurate and scientifically accepted conception (Mayer, 2002). However, this linear view has been critically examined by researchers who emphasize the **coexistence of multiple conceptual frameworks**, particularly in young learners. The intuitive knowledge structures—formed to formal instruction—often persist alongside newly acquired scientific concepts, resulting in hybrid or synthetic models rather than wholesale replacement (Vosniadou, 2007; Vosniadou & Skopeliti, 2014).

About a decade ago, the very notion of "CC" was challenged. Potvin (2013) proposed the **conceptual prevalence model**, which suggests that competing conceptions may coexist, with one becoming more dominant depending on context and instructional support. Empirical evidence supporting this model has been presented by researchers (Potvin et al., 2015) who demonstrated its explanatory power in classroom settings. It is essential to underscore that these theoretical perspectives are deeply intertwined with instructional practices. CC theorists differ in how they interpret learners' naïve conceptions and the mechanisms by which these are reorganized in response to new information. These differences reflect distinct **epistemological assumptions** and carry significant **pedagogical implications**—particularly in designing interventions that foster meaningful restructuring of prior knowledge. The following subsections explore these conceptual change (CC) theories in greater depth, highlighting their relevance to classroom teaching strategies and learners' cognitive development.

4.2.1. The 'Classical Approach' to Conceptual Change

Posner et al. (1982) proposed the most prominent model of CC. This model, which was mainly inspired by the Piagetian (Piaget, 1964) concept of accommodation and by the Khunian (Khun, 1970) concept of scientific revolution, addresses the problem of making learners modify the "misconceptions" they hold about how the physical world works (Potvin, 2013). Among the models that belong to the classical tradition, Nussbaum and Novick's (1982) model of CC is worth mentioning, together with the model of Posner et al. (1982). The classical model suggests that teachers should expose alternative frameworks, create a conceptual conflict, and encourage accommodation. According to Posner et al. (1982), four essential conditions must be satisfied for CC to occur. Their model emphasizes that learners must first experience *dissatisfaction* with their existing conceptions, recognizing limitations or inconsistencies in their prior understanding. Second, the new concept introduced by the teacher must be *intelligible*—clearly articulated and comprehensible to the learner. Third, the proposed idea must be *plausible*, meaning it should align with the learner's existing knowledge and appear logically sound. Finally, the new concept must demonstrate *fruitfulness*, offering explanatory power and the potential to generate further inquiry or problem-solving. These conditions collectively underscore the cognitive and pedagogical dynamics required to facilitate meaningful shifts in students' scientific understanding.

The theoretical framework, also called the 'classical approach' to CC, became the leading paradigm that guided research and instructional practices in science education for many years. Although there are amendments made today, various early participants in CC research were influenced by this approach to CC.

4.2.2. Framework Theory of Conceptual Change

Learning science requires fundamental ontological, epistemological, and representational changes (Vosniadou & Skopeliti, 2014). CCs are gradual affairs rather than sudden shifts (Vosniadou, 1999). These CCs require extended time to be achieved, giving rise to fragmentation and synthetic conceptions, which result from the assimilation of scientific information (Vosniadou & Skopeliti, 2014). The framework theory view (Vosniadou et al., 2008) argues that young children's experiences are organized into coherent structures that serve to provide explanations of their world. It is these frameworks that later undergo considerable restructuring (Vosniadou et al., 2008). The framework theory approach to CC envisages that a new idea, which fails to corroborate with what is already in the student's mind, is more complex and time-consuming to understand than the idea that supports the existing mental structure of students. Moreover, it explains the formation of 'synthetic models' resulting from learners' efforts to merely append the new information to existing but unsuited knowledge structures, which are known as alternative conceptions or misconceptions. Students create such a synthetic model to be effective in reconciling the conflicting information. As proposed by Vosniadou (1994), students do this when they learn about something that contradicts a piece of information that has already been integrated into the existing knowledge structure.

4.2.3. Knowledge in Pieces Theory

In the domain of conceptual change (CC) research, there remains a notable lack of precision in defining what constitutes a concept (diSessa, 2002). Effecting change without a clear understanding of what needs to be changed poses a fundamental challenge. This ambiguity complicates the selection of appropriate empirical methods and the development of effective instructional strategies to support CC (diSessa & Sherin, 1998). According to diSessa's framework, novice knowledge comprises elemental units referred to as "phenomenological primitives" or "p-prims," which emerge from learners' direct interactions with the physical world (diSessa, 2008, p. 40). CC, in this view, involves the integration of these pre-conceptual "knowledge pieces" into more sophisticated and coherent knowledge structures. Crucially, these emergent structures must be anchored in scientific concepts, distinguishing them from naïve or intuitive understandings.

diSessa and colleagues argue that knowledge cannot be adequately represented by a single type of mental entity, as traditionally assumed in concept-based models (diSessa et al., 2002). What is commonly referred to as a scientific concept should instead be understood as a dynamic system composed of numerous interacting elements of diverse types (diSessa, 2002). From this perspective, CC entails the modification, reorganization, and recombination of various mental entities in complex and context-sensitive ways. Given this theoretical stance, research in CC should prioritize the identification and characterization of the different types of mental entities involved in learning.

4.2.4. Ontological Category View of Conceptual Change

Chi et al. (1994) conceptualize conceptual change (CC) through an ontological lens, emphasizing that learners must reconceptualize how they categorize concepts. From this perspective, non-scientific conceptions are not merely incorrect—they belong to fundamentally different ontological categories. Effective learning thus requires a shift from these non-scientific categories to scientifically endorsed ones. Building on this framework, Chi and Roscoe (2002) argue that learners strive to construct accurate mental models of how phenomena operate. When these models are grounded in misconceptions, the erroneous conceptions must be replaced rather than refined. In their view, CC is a radical process involving the removal of misconceptions and the construction of scientifically valid conceptions to support deep understanding.

A misconception, in this context, is defined as a miscategorized concept—an idea placed within an inappropriate ontological category. Consequently, CC entails reassigning the concept to its correct category, thereby transforming the learner's mental model from one that is internally inconsistent to one that is coherent and scientifically adequate. This ontological approach underscores the importance of identifying and addressing the categorical nature of learners' conceptions. It suggests that instructional strategies should not only correct surface-level misunderstandings but also facilitate deeper reclassification of concepts within appropriate scientific frameworks.

4.2.5. Sociocultural View of Conceptual Change

The sociocultural approach to conceptual change (CC) is rooted in the premise that human cognition is inherently mediated and inseparable from the social, cultural, and historical contexts in which it unfolds (Wertsch, 1991). Central to this tradition is the notion of mediation—particularly through cultural tools and tool-mediated actions—which shape both the process and content of learning. From this perspective, CC involves the transformation of individual cognitive understandings (intramental processes) as well as the evolution of shared, socially mediated conceptual practices within a learning community (intermental processes) (Hall & Jurow, 2015). Sociocultural theory, when applied to science education, emphasizes that learning is situated within the specific social and cultural contexts accessible to the learner (Murphy, 2012). As Vygotsky (1978) posits, learning initially occurs between individuals and is subsequently internalized, with language serving as a primary mediational tool for organizing intellectual activity.

This outlook necessitates multi-layered analysis to understand how concepts are enacted in practical activity and how conceptual practices shift over time. CC, in this view, is closely tied to the development of tool-using practices that are embedded in the cultural routines of a community (Ivarsson et al., 2002). Shared social practices particularly discourse practices that function as cultural tools—play a pivotal role in shaping conceptual understanding (Kelly & Green, 1998). Thus, CC is not confined to the internal cognitive restructuring of individual learners. Rather, it emerges through dynamic interactions among learners, cultural tools, and social agents within educational communities. What evolves is not only the learner's internal understanding but also how cultural tools are appropriated and reconfigured across diverse learning environments.

4.2.6. Conceptual Prevalence Model

The conceptual prevalence model challenges traditional views of CC by proposing that multiple conceptions can coexist within learners, with one becoming dominant depending on context and instructional cues (Potvin, 2013). The conceptual prevalence model is best described as a theoretical framework, rather than a fully formalized theory in the classical scientific sense. It is a theoretical refinement of existing CC models, particularly to address limitations in how traditional models treat misconceptions and cognitive conflict (Potvin, 2013). It builds on empirical findings and neuro-educational insights to propose that multiple conceptions can coexist, with one prevailing depending on context rather than being replaced outright. Unlike classical models that emphasize cognitive conflict and replacement of misconceptions, the prevalence model embraces representational pluralism, acknowledging that learners may flexibly shift between intuitive and scientific ideas without necessarily discarding the former. An empirical study (Potvin et al, 2015) demonstrated the model's superiority in real classroom settings, showing that sequencing instruction to allow conceptual coexistence—rather than forcing early conflict—can lead to more effective learning outcomes. This approach reframes CC as a dynamic process of conceptual negotiation and contextual activation, offering valuable implications for science education and curriculum design (Potvin, 2023). This model is a pedagogically significant theoretical orientation that encourages tolerance for cognitive diversity and strategic instructional design.

These frameworks collectively reveal conceptual change (CC) as a multifaceted and dynamic process, with each offering distinct insights into how learners restructure their understanding. The Classical Approach (Posner et al., 1982) foregrounds cognitive conflict and the necessity

Table-1: *Comparative Overview of Conceptual Change Theories*

Theory/perspective	Core Assumption	Mechanism of Change	Pedagogical Implications
Classical Approach	Misconceptions are replaced through cognitive conflict (Posner et al., 1982).	Learners experience dissatisfaction with prior conceptions and adopt new ones that are intelligible, plausible, and fruitful.	Design instructions to provoke cognitive conflict, present scientifically robust alternatives, and emphasize their explanatory power.
Framework Theory	Learners possess intuitive frameworks that are gradually restructured (Vosniadou, 1994).	Conceptual change occurs via assimilation and restructuring, often involving ontological shifts.	Scaffold learning to address deep-seated presuppositions over time, allowing gradual conceptual reorganization.
Knowledge in Pieces	Knowledge consists of fragmented p-prims that can be integrated into coherent systems (diSessa, 2002).	Change involves reorganizing elemental knowledge units into scientifically coherent structures.	Use context-sensitive tasks to foster coherence and support the integration of fragmented ideas.
Ontological Category View	Misconceptions arise from assigning concepts to incorrect ontological categories (Chi et al., 1994).	Conceptual change requires re-categorizing ideas into appropriate scientific ontologies.	Employ analogies, metaphors, and explicit instruction to guide learners through ontological reclassification.
Sociocultural View	Learning is mediated by social interaction and cultural tools (Vygotsky, 1978).	Concepts are internalized through discourse, collaboration, and engagement with cultural artifacts.	Facilitate collaborative learning environments and leverage culturally relevant tools and practices.
Conceptual Prevalence Model	Multiple conceptions coexist; dominance is context-dependent (Potvin, 2013).	Scientific conceptions are activated by contextual cues without necessarily displacing intuitive ones.	Sequence instruction to support conceptual coexistence, minimize early conflict, and promote flexible reasoning.

of structured conditions for conceptual replacement. In contrast, Framework Theory (Vosniadou et al., 2008) emphasizes the gradual reorganization of coherent, intuitive belief systems. Knowledge in Pieces (diSessa, 2002) conceptualizes learning as the integration of fragmented, context-sensitive knowledge elements, while the Ontological Category View (Chi et al., 1994) focuses on the reclassification of concepts into fundamentally different ontological categories. The Sociocultural View (Vygotsky, 1978) situates conceptual change within socially mediated interactions and cultural tools, and the Conceptual Prevalence Model (Potvin, 2013) advocates for representational pluralism, acknowledging the coexistence of competing conceptual frameworks. Pedagogically, these theories suggest differentiated strategies: inducing cognitive conflict (Classical), scaffolding long-term restructuring (Framework), fostering coherence among knowledge elements (Knowledge in Pieces), facilitating ontological shifts (Ontological), leveraging collaborative discourse and cultural mediation (Sociocultural), and sequencing instruction to support conceptual coexistence (Prevalence). Despite their contributions, significant gaps remain in synthesizing these perspectives into an integrative model and in addressing the role of cultural diversity and contextual variability in CC processes. Also, the summary table above on theories puts ideas concisely.

4.3. Misconceptions in Chemistry and the Promise of Conceptual Change Approaches

Students' misconceptions in chemistry remain a prevalent impediment to deep scientific understanding, often rooted in intuitive reasoning, prior knowledge, and fragmented conceptual frameworks. Contemporary research affirms that conceptual change approaches—grounded in constructivist pedagogy—offer a potent remedy to these cognitive distortions. Ginyigazi et al. (2024) demonstrated that implementing a conceptual change strategy markedly enhanced learners' grasp of quantitative chemistry domains such as stoichiometry and chemical equations, with post-intervention assessments revealing substantial gains in scientific accuracy. Sarwar et al. (2024) further validated the efficacy of the conceptual change approach using concept mapping and conceptual change texts in nanoscale science, showing how these strategies catalyze cognitive restructuring and foster coherent mental models. A meta-analysis by Pacaci and Ustun (2024) corroborated these findings, reporting a robust effect size ($g = 1.10$) for conceptual change strategies—particularly those invoking cognitive conflict, bridging analogies, and ontological shifts—underscoring their transformative impact across science education. Meanwhile, Suparman et al. (2024) identified persistent misconceptions in chemical equilibrium, covalent bonding, acid-base theory, and material classification, advocating for targeted instructional interventions. Kayima (2025) emphasized the role of learners' interpretive frames and prior beliefs in shaping their conceptual trajectories, urging educators to leverage these cognitive anchors to facilitate meaningful change. Iter (2024), through empirical analysis at Palestine Technical University, revealed alarming rates of misconception—ranging from 53.9% to 84.6%—in topics such as specific heat versus temperature and solution saturation, reinforcing the imperative for diagnostic teaching and responsive curriculum design.

4.4. Pedagogical Pathways for Advancing Conceptual Understanding in Chemistry Classrooms

Pedagogical pathways or instructional strategies for promoting CC in chemistry classrooms focus on helping students revise or replace their misconceptions with scientifically accurate concepts by engaging them in active cognitive processes through the theoretical lenses discussed in the previous section. The strategies help students distinguish between prior conceptions and new scientific concepts, leading to cognitive restructuring. The approaches emphasize different conditions, like those reflected in the classical model. Studies show that CC strategies improve student learning outcomes compared to conventional methods (Swafiyah et al., 2023). In this sub-section, some CC strategies are discussed.

4.4.1. Conceptual Change Texts and Conceptual Change

Conceptual Change Texts (CCTs) are deliberately crafted to challenge learners' entrenched misconceptions and facilitate their transition toward scientifically validated understandings. In contrast to conventional instructional texts (traditional texts), which typically convey content in a neutral, expository format devoid of engagement with learners' prior cognitive frameworks, CCTs strategically introduce conceptual conflict. Traditional texts are mainly expository and focus on presenting scientific information for students to memorize and reproduce, often without explicitly addressing students' prior misconceptions. Traditional texts usually deliver content in a one-way manner, emphasizing facts and procedures without engaging students in reflecting on or challenging their pre-existing ideas. Traditional textbooks have been criticized for their expository nature, their difficult lexical structure, and for their lack of evidence to support claims (Bars, 2014). Recent frameworks for science education in the United States emphasise the need for students to engage with texts that better reflect the scientific enterprise. Specially designed CC texts that explicitly address students' misconceptions by confronting them with scientific explanations and evidence, helping students restructure their understanding. Different studies indicate that CC texts are effective in improving the understanding of chemistry concepts compared to conventional instruction (Özmen, 2007; Ültay, 2015; Sendur, 2013). For instance, Özmen (2007) demonstrated that CC texts significantly enhanced students' grasp of the particulate nature of matter by addressing misconceptions through targeted refutation strategies. Ditto, Sendur (2013) also reported that CC texts helped students restructure their prior knowledge and achieve more scientifically accurate conceptions in thermodynamics.

4.4.2. Laboratory Activities and Conceptual Change

Laboratory activities play a pivotal role in fostering CC in science education by bridging abstract theories with tangible experiences. Rooted in constructivist and CC models (Posner et al., 1982), hands-on experiments allow learners to confront and revise misconceptions through direct observation, manipulation, and reflection. Studies show that when students engage in inquiry-based laboratory work—such as testing chemical reactions or modeling atomic structures—they are more likely to restructure naïve conceptions and adopt scientifically accurate frameworks (Westbrook & Rogers, 1996). However, challenges such as limited resources, inadequate infrastructure, and insufficient teacher training—particularly in developing contexts (Like Ethiopia) can hinder the effectiveness of laboratory instruction (Alema et al., 2024). To maximize impact, laboratory activities must be strategically integrated with conceptual scaffolding, diagnostic assessment, and reflective dialogue, ensuring that practical work serves not just as demonstration but as a catalyst for deep cognitive transformation.

4.4.3. Concept Cartoons and Conceptual Change

Concept cartoons have emerged as an effective pedagogical tool for promoting CC, particularly in science education. These visual prompts present conflicting viewpoints on scientific phenomena in a cartoon format, encouraging learners to confront their own misconceptions and engage in reflective dialogue. Research by Kumi-Manu (2021) in Ghanaian junior high schools demonstrated that concept cartoons helped students identify and revise erroneous ideas through peer discussion and comparison with scientifically accurate explanations. Similarly, Taşlıdere (2021) found that CC texts enriched with concept cartoons significantly improved pre-service teachers' understanding of mechanical waves, outperforming simulation-based instruction. Through fostering cognitive conflict in a non-threatening, engaging manner, concept cartoons align well with constructivist principles and offer a low-cost, high-impact strategy for facilitating conceptual restructuring in diverse educational contexts.

4.4.4. Concept Mapping and Conceptual Change

Concept mapping is a powerful metacognitive strategy that supports CC by helping learners visualize relationships among scientific ideas and restructure their understanding. Rooted in constructivist theory, concept maps allow students to externalize their prior knowledge, identify misconceptions, and integrate new information into coherent frameworks. Gravett and Swart (1997) demonstrated that concept mapping can be used before instruction to elicit learners' existing conceptions, during instruction to guide knowledge construction, and after instruction to assess CC and monitor cognitive development. More recently, Sarwar et al. (2024) applied concept mapping alongside CC texts to address misconceptions in nanoscale science, showing that this dual approach fosters critical reflection, peer dialogue, and deeper understanding of complex phenomena. Through making learners' thinking visible and promoting active engagement, concept mapping serves as both a diagnostic and transformative tool in science education.

4.4.5. Demonstrations and Conceptual Change

Demonstrations serve as a vital instructional strategy for facilitating CC, particularly in science education, where learners often hold persistent misconceptions. By visually and experientially presenting scientific phenomena, demonstrations create cognitive conflict that challenges students' intuitive beliefs and prompts re-evaluation. Neo and Yap (2009) developed the PORE model—Predict, Observe, Resolve, Extendas a framework for demonstration-based CC instruction, showing its effectiveness in improving students' understanding of electromagnetism and electromagnetic induction. Their study revealed that structured demonstrations, when paired with guided inquiry and reflection, significantly enhance learners' ability to reconcile prior misconceptions with scientific explanations. Moreover, the use of cognitive conflict level tests provided insights into how demonstrations trigger conceptual restructuring. When strategically designed, demonstrations not only clarify abstract concepts but also act as catalysts for deeper cognitive engagement and long-term conceptual transformation.

4.4.6. Analogies and Conceptual Change

Analogies serve as powerful cognitive tools in science education, particularly in facilitating CC within chemistry classrooms. They enable students to relate unfamiliar scientific concepts to familiar, everyday experiences, thereby making abstract or complex ideas more intelligible and accessible. This relational mapping between a known domain (the analog) and an unknown domain (the target) helps bridge cognitive gaps and supports the restructuring of prior knowledge. As Hanson and Seheri-Jele (2018) demonstrated, analogies—when paired with concept maps—can significantly enhance students' understanding of acid-base strengths by guiding them from naïve conceptions toward scientifically accurate frameworks. Their study revealed that CC-oriented instruction, enriched with analogical reasoning, led to improved learning outcomes compared to traditional methods.

Orgill and Bodner (2004) further emphasize that analogies, when used effectively, can promote meaningful learning by activating students' prior knowledge and encouraging deeper engagement with scientific content. However, they caution that poorly constructed or misaligned analogies may reinforce misconceptions rather than resolve them, underscoring the need for deliberate instructional design. Lalami (2024) adds that the effectiveness of analogies depends on the degree of structural similarity between the analog and target domains. In chemistry, where abstract concepts such as molecular interactions, reaction mechanisms, and atomic structure often challenge learners, analogies can demystify content by anchoring it in familiar cognitive schemas. For example, likening electron movement to traffic flow or comparing chemical bonding to interpersonal relationships can foster intuitive understanding and stimulate CC. Moreover, analogies align well with constructivist pedagogies, which advocate for learner-centered approaches that build upon existing mental models. Through facilitating the transition from intuitive, experience-based reasoning to formal scientific understanding, analogies play a pivotal role in transforming misconceptions into meaningful learning. Also, the summary table below on the strategies puts ideas succinctly.

Table-2: *Conceptual Change Strategies in Science/Chemistry Education*

Strategy	Core Purpose	Mechanism of Conceptual Change	Key Studies / Evidence
Conceptual Change Texts (CCTs)	Dislodge entrenched misconceptions through structured refutation and explanatory narratives.	Introduce conceptual conflict by explicitly confronting alternative conceptions, followed by scientifically grounded explanations to foster dissatisfaction and cognitive accommodation.	Özmen (2007) on particulate nature; Ültay et al. (2015) on REACT strategy for solutions; Sendur & Toprak (2013) on alkenes; Beerenwinkel et al. (2011) on particle models; Özmen et al. (2009) on chemical bonding; Alparslan et al. (2003) on solutions, Bealchew et al. (2018) on hydrocarbon

Strategy	Core Purpose	Mechanism of Conceptual Change	Key Studies / Evidence
			concepts achievement, Belachew et al. (2019) on hydrocarbon concepts motivation, Bealchew (2020) on hydrocarbon concepts understanding
Laboratory Activities	Translate abstract theories into experiential learning to revise naïve conceptions.	Facilitate direct manipulation and observation, generating cognitive dissonance through empirical contradictions that prompt model refinement.	Cobern (1996) on worldview; Brhane et al. (2025) on Ethiopian classrooms; Adadan (2013) on particle theory; Barthlow & Watson (2014) on reducing misconceptions.
Concept Cartoons	Stimulate dialogue and reflection through visual, low-threat provocations.	Present divergent viewpoints via cartoon characters to elicit peer discussion, exposing and challenging misconceptions in a socially safe format.	Kumi-Manu (2021) in Ghanaian schools; Taşlıdere (2021) on mechanical waves; Balim et al. (2008) on pressure; Gafoor & Shilna (2013) on chemistry engagement.
Concept Mapping	Foster metacognitive restructuring by visualizing conceptual relationships.	Externalize prior knowledge into hierarchical frameworks, revealing gaps and enabling integration of new ideas for ontological coherence.	Gravett & Swart (1997); Sarwar et al. (2024); Kaya (2008); Talbert et al. (2020)
Demonstrations	Visually disrupt intuitive beliefs and scaffold inquiry-based reasoning.	Create immediate cognitive conflict through observable phenomena, followed by structured reflection (e.g., PORE model) to reconcile discrepancies and build explanatory models.	Neo & Neo (2009) on PORE; Syuhendri (2023) on attitudes; Domin (2007) on lab perceptions.
Analogies	Bridge abstract concepts with familiar experiences to enhance relational understanding.	Map familiar source domains onto abstract targets, enabling structural alignment and relational reasoning to restructure misconceptions.	Hanson & Seheri-Jele (2018); Orgill & Bodner (2004); Lalami (2024); Çalik et al. (2009); Sarantopoulos & Tsaparlis (2004).

4.5. Limitations of Conventional Teaching Methods and Importance of Pedagogical Innovation

Conventional pedagogical approaches—predominantly characterized by teacher-centered delivery, rote memorization, and passive student engagement—have long prevailed in educational settings. While such methods may offer structural clarity and facilitate content transmission, they frequently fall short in cultivating deep conceptual understanding, critical inquiry, and sustained learner engagement. These approaches tend to position students as passive recipients rather than active constructors of knowledge, thereby impeding cognitive development and the possibility of meaningful CC (Falasi, 2024). Furthermore, they often neglect the diverse cognitive profiles, motivational dispositions, and cultural backgrounds of learners, resulting in pedagogical misalignment and diminished inclusivity (Alessa & Hussein, 2023). The rigidity of standardized curricula and inflexible instructional formats further exacerbates this disconnect, particularly in multicultural contexts such as Ethiopia, where contextual relevance is paramount. Additionally, the absence of timely formative feedback and dialogic interaction undermines opportunities for diagnostic assessment and the correction of entrenched misconceptions. These limitations underscore the urgent imperative for pedagogical innovation—embracing learner-centered, constructivist, and culturally responsive approaches—to meet the evolving epistemological needs of diverse learners (Awang et al., 2025).

Pedagogical innovation has emerged as a necessary response to the limitations of traditional teaching methods, offering transformative potential through learner-centered, constructivist, and technology-enhanced approaches. By prioritizing active learning and conceptual engagement—through strategies such as problem-based learning, flipped classrooms, and analogical reasoning—innovative pedagogy fosters deeper cognitive restructuring and meaningful understanding (Singh & Goyal, 2024). It also embraces culturally responsive instruction, integrating indigenous knowledge systems, linguistic diversity, and contextual relevance, which is particularly vital in Ethiopian classrooms where educational equity and cultural resonance are paramount (Bekmanova, 2019). Furthermore, flexible and adaptive learning environments, supported by blended modalities and digital tools, empower students to navigate personalized learning trajectories that align with their pace, style, and needs. Empirical research consistently affirms that such innovations lead to improved retention, enhanced conceptual clarity, and heightened learner motivation, positioning educators not merely as transmitters of knowledge but as facilitators of transformative learning experiences (Herodotou et al., 2019).

4.6. Advantages of the conceptual change perspective

In response to the limitations of conventional teaching methods, the CC perspective offers a transformative approach to science education, particularly in chemistry, by prioritizing the restructuring of students' prior knowledge. Rather than treating misconceptions as errors to be corrected, CC pedagogy views them as starting points for deeper cognitive engagement. This approach encourages learners to confront and reflect on their existing mental models, fostering metacognitive awareness and epistemological growth. Instructional strategies such as CC texts, analogies, and guided inquiry are designed to provoke cognitive conflict and facilitate the transition from naive to scientifically accurate understanding. As Posner et al. (1982), and Duit and Treagust (2003) argue, meaningful learning occurs when students actively reorganize their conceptual frameworks in response to compelling evidence and reasoning.

Moreover, CC pedagogy aligns seamlessly with constructivist and culturally responsive teaching practices. In diverse educational contexts, such as Ethiopia, where learners bring rich experiential knowledge shaped by local languages, traditions, and worldviews, CC strategies can bridge the gap between global scientific paradigms and indigenous understandings. By integrating familiar analogies, contextually relevant demonstrations, and dialogic learning environments, educators can make abstract chemical concepts more accessible and resonant. Empirical studies have shown that such approaches not only improve conceptual clarity but also enhance student motivation and long-term retention (Hanson & Seheri-Jele, 2018; Orgill & Bodner, 2004). Thus, embracing CC as a pedagogical foundation is not merely an instructional choiceit is a strategic imperative for cultivating scientifically literate, critically reflective learners.

4.7. Challenges in Implementing the Conceptual Change Approach

The Conceptual Change (CC) approach heralds the potential for profound cognitive transformation, yet it is frequently diminished to mere rhetorical ornamentation. While educators speak earnestly of "dislodging misconceptions," the reality of classrooms governed by rote assessments and inflexible curricular structures leaves little room for genuine epistemological engagement. In the absence of systemic reform—spanning teacher preparation, curriculum design, and assessment Conceptual Change risks devolving into a pedagogical mirage (failing to deliver meaningful impact): extolled in scholarly discourse, but conspicuously absent from the lived realities of instructional practice. The remedy for this is understanding the challenges, and addressing them. The implementation of the CC approach in education—particularly within science and mathematics domains—poses profound pedagogical and epistemological challenges (Nadelson et al., 2018). Foremost among these is the persistence of deeply entrenched misconceptions that learners acquire through everyday experiences and linguistic conventions. Such intuitive beliefs, like the notion that heavier objects fall faster than lighter ones, often remain impervious to correction even when confronted with empirically validated scientific explanations. Effective conceptual change necessitates more than the transmission of accurate information; it requires the deliberate induction of cognitive dissonance, the facilitation of metacognitive reflection, and the cultivation of epistemological awareness (Chi & Roscoe, 2002). Teachers must be adept at diagnosing misconceptions, orchestrating inquiry-driven discourse, and scaffolding learners' transitions from naïve frameworks to scientifically coherent understandings, a process that is both cognitively demanding and pedagogically intricate.

Compounding these challenges are systemic constraints embedded within traditional curricula and assessment regimes, which tend to valorize rote memorization and procedural fluency over deep conceptual restructuring. Standardized evaluations seldom capture the nuanced evolution of learners' cognitive schemas, thereby undermining the diagnostic and formative potential of CC-based instruction. Furthermore, many educators lack formal exposure to conceptual change theory and its associated pedagogical strategies, such as ontological category shifts and analogical reasoning (Taşdere, 2023). The absence of institutional support—manifested in limited professional development, rigid curricular frameworks, and inadequate assessment tools—risks relegating the CC approach to the periphery of educational practice. Addressing these impediments demands a concerted effort across policy, research, and instructional design to embed conceptual change as a foundational principle of science education reform (Ashwin, 2018; Duit & Treagust, 2011; Grillo, 2024; Nadelson et al., 2018).

5. Conclusion

The scholarship on conceptual change (CC) has evolved from a revolutionary metaphor—borrowed from Kuhn—into empirically grounded and theoretically rich constructs in science education. What began as a cognitive narrative of rational replacement (Posner et al., 1982) has expanded into a multidimensional framework where dissatisfaction intertwines with desire, conflicting ideas coexist in the coexistence model, and individual cognition is inseparable from the cultural tools and social voices that mediate it. The evidence is unequivocal. Chemistry misconceptions are not mere errors but systematically adaptive knowledge structures. They persist because they once served a purpose. Only when instruction renders them intelligibly unsatisfactory, plausibly replaceable, and fruitfully extendable—or, under prevalence models, contextually suppressible—do learners willingly renegotiate their conceptual allegiance.

Meta-analytic findings leave little room for doubt. CC-oriented pedagogies yield effect sizes that far exceed those of traditional exposition (Pacaci & Ustun, 2024). Whether through the refutational clarity of Conceptual Change Texts, the gentle provocation of concept cartoons, the visceral dissonance of PORE demonstrations, or the structural resonance of well-chosen analogies, effective strategies share a common mark—they treat the learner not as a passive recipient, but as an active author of meaning. Yet the horizon remains open. We still lack a truly integrative model that synthesizes the six major theoretical strands (Classical Approach, Framework Theory, Knowledge in Pieces, Ontological Category View, Sociocultural View, and Conceptual Prevalence Model). Classrooms that honor both voices, allow them to engage in epistemic dialogue, and teach learners when and how to let the scientific voice speak loudest, will complete the conceptual change revolution that began in 1962 Until then, each lingering misconception reflects not a learner's failure, but the distance our pedagogical imagination has yet to travel.

6. Recommendations

Embed Conceptual Change Strategies in Curriculum Design

Curriculum frameworks for teacher education and chemistry instruction should be deliberately structured around CC principles. This involves identifying common misconceptions, sequencing content to provoke cognitive conflict, and embedding opportunities for epistemological reflection. Curriculum designers must integrate constructivist scaffolding, inquiry-based tasks, and diagnostic assessments that reveal students' prior conceptions. In the Ethiopian context and other contexts, aligning these strategies with national curriculum reform priorities ensures both pedagogical relevance and systemic coherence. CC should not be an add-on but a foundational lens through which curriculum goals, content organization, and instructional outcomes are defined.

Promote Reflective Teaching Practices

Reflective teaching is essential for fostering CC, as it enables educators to monitor students' cognitive progress and adapt instruction accordingly. Teachers should be trained to use formative assessments, student interviews, and classroom discourse to identify persistent misconceptions and respond with targeted interventions in chemistry. Reflective practice also involves examining one's own instructional assumptions and biases, particularly in culturally diverse settings. In Ethiopia and other contexts, embedding reflective protocols carefully into teacher education programs—such as lesson study, peer observation, and action research—can cultivate a professional culture of inquiry and responsiveness, ultimately improving instructional quality and student outcomes.

Design Meaningful Professional Development for Teachers

Professional development is critical for equipping chemistry teachers and educators with both theoretical knowledge and practical tools. These are needed to implement CC pedagogy effectively. Workshops, mentoring programs, and training sessions should focus on diagnostic strategies, concept mapping, and culturally responsive instruction. Training should be ongoing and built into school systems. This allows teachers to experiment, reflect, and improve their practice over time. Collaboration between universities, teacher training colleges, and regional education bureaus is also important. It helps ensure that professional development is meaningful, context-sensitive, and aligned with national education goals.

Encourage Research-Practice Integration

Bridging the gap between CC theories/strategies and classroom practice requires robust research that examines how these strategies function in diverse educational contexts. Action research, case studies, and classroom-based experiments can generate insights into the effectiveness, challenges, and adaptations of CC pedagogy. Educators should be empowered to participate in research as co-investigators, contributing local knowledge and classroom experience. Findings should inform policy, curriculum design, and teacher training, creating a feedback loop between theory and practice.

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