The Essence, Challenges, and Optimization Strategies for Integrating Interdisciplinary Thematic Instruction into Chemistry Education

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Abstract. Interdisciplinary thematic instruction is a key approach for implementing core competencies in chemistry education in the new era. This paper explores the connotations, challenges, and pathways of interdisciplinary thematic instruction in chemistry education, clarifying its core essence as being premised on real-world problems, linked by interdisciplinary concepts, and grounded in interdisciplinary thinking. It identifies current issues in practice, including insufficient top-level design, misaligned teacher philosophies, and superficial classroom implementation; It proposes optimizing implementation through three approaches: strengthening top-level coordination, establishing the philosophy of "discipline-based, cross-disciplinary integration," and deepening classroom practice reforms. These measures aim to shift chemistry's interdisciplinary teaching from formality to substance and enhance the discipline's effectiveness in fostering student development.

Keywords: interdisciplinary thematic teaching; chemistry education; core competencies.

1 Introduction

Interdisciplinary education has become a key direction for educational reform and curriculum development in the new era; however, its theoretical positioning and practical models within subject-based instruction still require further clarification. From the perspective of existing research, interdisciplinary education manifests not only in the integration of curriculum content and thematic design but also in the transformation of learning approaches and the cultivation of thinking skills.

Currently, chemistry education faces numerous practical challenges in advancing interdisciplinary teaching[1]. Based on this, this paper takes chemistry education as its starting point and regards interdisciplinary thematic teaching as a key pathway to promote students' cognitive development and enhance their competencies. It delves into its connotations, characteristics, practical challenges, and optimization strategies,

B. Kanoksilapatham et al. (eds.), *Proceedings of the 2026 2nd International Conference on Education Reform, Ideology and Politics (ERIP 2026)*, Advances in Social Science, Education and Humanities Research 1028,
https://doi.org/10.2991/978-2-38476-601-7_42

with the aim of providing theoretical guidance for the effective implementation of interdisciplinary concepts in chemistry classrooms.

2 The Core Essence of Interdisciplinary Theme-Based Instruction in Chemistry Education

The core essence of interdisciplinary theme-based instruction in chemistry education is rooted in the inherent integration of "interdisciplinary instruction"and "theme-based instruction." The former emphasizes transcending disciplinary boundaries and integrating multidisciplinary ways of thinking to solve complex problems[4]. the latter advocates using socially significant core themes as a hub to unify teaching objectives and content. While sharing the same purpose but differing in approach, these two concepts jointly determine that this teaching model must, while upholding disciplinary perspectives, achieve the deep integration of multidisciplinary knowledge through thematic frameworks. Specifically within the context of chemistry education, its core essence is manifested in the dialectical unity of three dimensions.

First, it must be based on authentic interdisciplinary problems. Interdisciplinary thematic instruction is not a haphazard combination of subject knowledge, but rather a comprehensive approach to teaching based on the problem itself. Real-world problems often span multiple disciplinary fields, and a single discipline—such as chemistry—cannot fully explain or solve them. Therefore, only problems with inherently interdisciplinary attributes can serve as a valid basis for interdisciplinary teaching. For example, "Why does sodium chloride dissolve in water?" is a purely chemical question that does not require an interdisciplinary approach; whereas "Why does 84 Disinfectant kill bacteria and disinfect?" integrates chemical principles with knowledge of biological structures, possessing a natural interdisciplinary nature—which is the very foundation upon which interdisciplinary thematic teaching is built.

Second, interdisciplinary concepts serve as the connecting thread. Interdisciplinary concepts are overarching concepts that transcend the core concepts of individual disciplines; they bridge the knowledge systems and modes of thinking across multiple disciplines, providing the intrinsic logic for disciplinary integration. For instance, the interdisciplinary concept of "structure and function" manifests in chemistry as the idea that a substance's structure determines its properties and applications[2], and in biology as the idea that an organism's structure determines its physiological functions. Under this single concept, the two disciplines can achieve deep integration.

Third, interdisciplinary thinking is the essence. The fundamental purpose of interdisciplinary thematic instruction in chemistry education lies not in expanding knowledge content, but in cultivating students ability to integrate multidisciplinary perspectives and apply interdisciplinary thinking to solve complex problems. This mode of thinking represents the core value of interdisciplinary instruction and is its defining characteristic that distinguishes it from other teaching models. For example, in the "Carbon Neutrality and Low-Carbon Living" thematic learning module, students no longer analyze the transformation of carbon dioxide solely from the perspective of chemical reactions. Instead, they are able to think comprehensively by integrating perspectives from chemistry, environmental science, energy science, and other fields[3], thereby developing systematic interdisciplinary thinking through the process of solving real-world problems.

Therefore, interdisciplinary thematic teaching in chemistry education is a pedagogical approach grounded in the discipline of chemistry, driven by real-world problems, and centered on the core objective of cultivating interdisciplinary thinking.

3 Practical Challenges Facing Interdisciplinary Theme-Based Instruction in Chemistry Education

Against the backdrop of the ongoing deepening of curriculum reform, interdisciplinary theme-based instruction has become a key approach for chemistry education to foster core competencies. However, in practice, interdisciplinary theme-based instruction in chemistry still faces multiple constraints at the levels of school-wide coordination, teacher perception, and classroom implementation. Overall implementation remains subpar, with issues such as formalism, fragmentation, and superficiality, making it difficult to fully realize its educational value.

3.1 Inadequate Top-Level Design: Schools Lack Comprehensive Curriculum Coordination and Systematic Planning

As a systematic educational initiative, interdisciplinary thematic teaching relies heavily on well-established management systems and course implementation mechanisms at the school level. However, most schools have yet to develop mature institutional frameworks in this area, resulting in significant shortcomings in top-level design. Many schools have not integrated chemistry-based interdisciplinary thematic teaching into their overall curriculum planning, lacking a coherent set of objectives aligned with required courses, standardized teaching guidelines, and adequate support in terms of teacher training, laboratory equipment, and dedicated funding. Consequently, such interdisciplinary chemistry instruction often depends on individual teachers' personal enthusiasm, leading to fragmented and sporadic practices that struggle to become consistent and sustainable.

Taking the interdisciplinary thematic instruction on "Campus Water Quality Monitoring and Analysis" as an example, some schools have failed to conduct systematic curriculum planning and coordinate interdisciplinary teaching and research in advance. As a result, chemistry teachers find it difficult to effectively integrate content such as aquatic ecosystem analysis from biology and watershed hydrological characteristics from geography to conduct comprehensive project-based inquiry. They are forced to simplify teaching procedures and reduce the depth of inquiry, ultimately causing teaching activities to become mere formalities and failing to achieve the intended goals of cultivating comprehensive competencies.

3.2 Misconceptions Regarding Philosophy: Teachers' Misunderstandings of Interdisciplinary Instruction

Some teachers lack a clear understanding of the core essence of interdisciplinary thematic instruction, which has become the primary cognitive barrier hindering the high-quality development of interdisciplinary chemistry education, resulting in obvious cognitive misalignments and value-based confusion in teaching practice. On one hand, there is a tendency to cling to traditional disciplinary teaching paradigms, treating interdisciplinary instruction as an additional task on top of regular teaching, and neglecting its unique educational significance in breaking down knowledge barriers and cultivating students' comprehensive problem-solving abilities. On the other hand, there is a tendency to pursue superficial integration, equating interdisciplinary teaching simply with the accumulation of knowledge from multiple disciplines, and falling into the trap of formalism—teaching "interdisciplinary" for the sake of being interdisciplinary.

Taking the teaching of "Chemical Substances in Common Foods" as an example, some teachers merely mechanically piece together fragmented knowledge—such as the classification of nutrients from biological nutrition and dietary pairing recommendations from dietary health studies—or even turn chemistry classes into health education sessions. They fail to conduct in-depth exploration centered on the core concepts of chemistry—the structure, properties, and transformations of substances. They do not guide students to analyze the hydrolysis reactions of carbohydrates and fats from the perspective of chemical bonds, nor do they investigate the relationship between the mechanisms of food additives and safe dosage levels. Such practices not only severely undermine the discipline's foundational principles but also fail to achieve the organic integration and deep convergence of knowledge across different disciplines, ultimately falling short of the core competency development goals.

3.3 Weak Implementation: Classroom Quality and Educational Outcomes Need Improvement

In the practical implementation of interdisciplinary chemistry instruction, prominent issues such as vague objectives, superficial processes, and weak support systems are widespread[5], making it difficult to effectively ensure the overall quality of implementation. Most thematic designs lack a clear disciplinary logic and progression across grade levels; inquiry activities often remain at lower-order cognitive levels, failing to foster the development of students' higher-order thinking. At the same time, the lack of supporting systems—such as fragmented class time allocation, the absence of mechanisms for interdisciplinary teacher collaboration, and a one-dimensional evaluation system—further limits the effectiveness of teaching.

Taking the interdisciplinary theme activity "Preparation and Safe Use of Disinfectant" as an example, some classes are limited to simple experimental procedures—such as preparing disinfectant by electrolysis of saturated brine—failing to guide students in a deeper exploration of the nature of sodium hypochlorite's redox reaction. Nor do they integrate comprehensive inquiry with the mechanisms of microbial inactivation from biology or safety protection design from engineering. Teaching evaluations continue to rely solely on final experimental results, lacking formative assessments of students' investigative processes, problem-solving approaches, and teamwork skills. Consequently, interdisciplinary teaching has become merely a formality, failing to genuinely enhance students' comprehensive competencies.

4 Pathways to Optimizing Interdisciplinary Theme-Based Instruction in Chemistry Education

In light of the current challenges facing interdisciplinary theme-based instruction in chemistry—including issues in top-level design, conceptual understanding, and practical implementation—there is an urgent need to establish an improvement system that combines "top-down" systemic safeguards with "bottom-up" practical innovation. By refining curriculum management mechanisms, reshaping teachers' pedagogical philosophies, and deepening classroom practice reforms—a three-pronged approach—we can break through developmental bottlenecks, propel interdisciplinary thematic instruction in chemistry from "formal exploration" toward "substantive development," and truly realize the educational value of the discipline.

4.1 Strengthening Top-Level Design: Establishing a Systematic Curriculum Management and Support System

The key to overcoming leadership challenges lies in integrating interdisciplinary thematic instruction into the core agenda of school curriculum development and establishing a complete "planning–implementation–evaluation" cycle at the institutional level. Schools should assume a leading role in curriculum management by developing school-based implementation plans for interdisciplinary thematic instruction based on the core competencies of the chemistry discipline, clearly defining class schedules, thematic sequences, and resource allocation standards. At the same time, schools should establish interdisciplinary teaching and research communities to break down disciplinary barriers and provide organizational support for instructional implementation.

Schools can center their efforts around the core theme of "green chemistry" to design a progressive thematic framework spanning from "campus waste sorting and resource utilization" in middle school to "investigation and improvement of industrial wastewater treatment processes" in high school. They should also establish a system for regular interdisciplinary joint lesson planning sessions, supporting chemistry teachers in collaborating with biology and geography teachers to co-develop course resources and design inquiry-based tasks, thereby fundamentally addressing issues such as fragmented instruction and disjointed resources.

4.2 Clarifying Conceptual Understanding: Establishing a "Discipline-Based, Cross-Boundary Integration" Teaching Philosophy

The key to overcoming misconceptions lies in guiding teachers to grasp the dialectical unity of "disciplinary" and "interdisciplinary" approaches, and to reject the two extremes of "disciplinary supremacy" and "de-disciplinarization." Schools should utilize methods such as specialized training and demonstrations by distinguished teachers to help educators deeply understand that the essence of interdisciplinary teaching lies in "integration grounded in the discipline of chemistry." while treating knowledge from other disciplines as tools and support for broadening perspectives on solving chemical problems and enriching pathways for inquiry.

When designing the interdisciplinary theme "Galvanic Cells and New Energy Vehicles," the teaching core should be clearly defined as the "nature of redox reactions" and "principles of electrode reactions" from chemistry. Content from physics, such as "circuit connections and laws of energy conversion," and from geography, such as "regional energy distribution and sustainable development," should serve only as supplementary material to create authentic contexts and extend the application value. This design approach ensures that instruction consistently revolves around the essence of chemistry, truly achieving a deep integration that is "cohesive yet distinct, interdisciplinary yet grounded," and effectively fulfilling the cultivation goals of core chemical literacy.

4.3 Deepening Practical Reform: Enhancing the Quality of Classroom Instruction and Educational Effectiveness

To address the challenges in implementing interdisciplinary chemistry instruction, it is necessary to make concerted and systematic efforts across three core dimensions—objectives, process, and assessment—to drive a profound transformation in classroom teaching from knowledge transmission to the cultivation of competencies. In terms of goal setting, macro-level subject-specific core competency goals must be broken down into specific, integrated objectives that are observable, achievable, and assessable, thereby avoiding vague or overly broad goals. In terms of process design, instruction should be driven by complex problems in real-world contexts, guiding students to engage in inquiry-based and project-based higher-order thinking activities. In terms of assessment methods, we must move beyond the limitations of traditional paper-and-pencil tests and establish a comprehensive, multi-dimensional evaluation system that balances knowledge mastery, cognitive development, and practical skills.

In the interdisciplinary lesson "Chemical Reactions in the Kitchen," teachers can set specific objectives: applying the principles of double displacement reactions to analyze the mechanism of limescale removal (chemistry), and using solution concentration calculations to optimize the cleaning formula (mathematics). During the teaching process, students are organized into groups to conduct comparative experiments, record data, and write investigative reports.This approach not only evaluates core chemistry knowledge but also assesses students' interdisciplinary thinking and problem-solving abilities, thereby truly enhancing the effectiveness of instruction.

5 Conclusion

Interdisciplinary thematic instruction is a key approach for chemistry education in the new era to implement core subject competencies and address real-world problems. Its core principle lies in upholding the intrinsic nature of the chemistry discipline, using comprehensive themes rooted in real-world contexts as a driving force, and aiming to cultivate students' interdisciplinary thinking and comprehensive problem-solving skills, thereby achieving an organic and in-depth integration of multidisciplinary knowledge, methods, and thinking. Compared to traditional subject-based instruction, interdisciplinary thematic teaching breaks down disciplinary barriers, closely integrating abstract chemical concepts with students' life experiences and societal development needs, and providing students with authentic contexts in which to apply chemical knowledge to solve real-world problems. However, current interdisciplinary chemistry teaching practices still face numerous challenges: at the school level, there is insufficient top-level coordination, with a lack of systematic curriculum planning and institutional safeguards; at the teacher level, there are cognitive biases, making it difficult to strike a balance between disciplinary and interdisciplinary approaches; and at the classroom level, implementation remains superficial, with inquiry activities often confined to lower-order cognitive levels, failing to fully realize their unique educational value.

Promoting the high-quality development of interdisciplinary chemistry education requires collaborative efforts from multiple stakeholders and systematic measures. Schools should strengthen top-level curriculum design, integrate interdisciplinary teaching into the overall curriculum framework, and establish an integrated "planning-implementation-evaluation" operational mechanism; guide teachers to embrace the core philosophy of "discipline-based, cross-disciplinary integration," and enhance their interdisciplinary teaching capabilities through specialized training and joint teaching research; optimize classroom implementation pathways by breaking down macro-level competency goals into actionable instructional objectives, using real-world problems to drive higher-order inquiry, and establishing a diversified assessment system that balances knowledge mastery with skill development. Only in this way can interdisciplinary chemistry instruction move from formality to substance, comprehensively enhance students' overall competencies through the process of solving real-world problems, and truly realize the educational value of the chemistry discipline.

Author Contributions

Zhang Yujia conceived the idea of the study and wrote the paper. Hui Wang guided the revision of this paper.

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