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Problem Design Strategies in High School Chemistry Modeling Teaching

Liang Zhang
[1] College of Teacher Education, Southwest University, Chongqing 400715, China
[2] Shanxi Experimental Secondary School, Taiyuan 030031, Shanxi, China

Abstract: As one of the core competencies of the chemistry discipline under the new curriculum standards, the key to cultivating chemical modeling lies in placing students in real inquiry situations where they actively construct models. This paper aims to construct a progressive problem-chain design strategy of "phenomenon-driven, conflict-construction, and iterative refinement". Starting from real or abnormal chemical phenomena as the inquiry starting point, through carefully designing cognitive conflict problems, students are prompted to expose and reflect on the limitations of their initial models. Then, through a series of scaffolded and iterative problems, students are guided to independently modify, test, and generalize the models, achieving a spiral ascent from pre - scientific concepts to scientific models. It is hoped to provide front - line teachers with a set of operable and systematic problem - design methodologies.

Keywords: High school chemistry; Modeling teaching; Design strategies

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1. Introduction

With the deepening of the basic education curriculum reform in China, the Chemistry Curriculum Standards for General High Schools (Revised in 2020, 2017 Edition) has established five core competencies for the chemistry discipline, namely "macroscopic identification and microscopic analysis", "change concept and equilibrium thinking", "evidence reasoning and model cognition", "scientific inquiry and innovation awareness", and "scientific spirit and social responsibility". Among them, "evidence reasoning and model cognition", as the core bridge connecting the chemical discipline knowledge system and the development of students' scientific thinking, has been elevated to an unprecedented level of importance. Chemical modeling is not only the key path for the formation of model-cognition literacy but also the fundamental way for students to understand the essence of chemistry, develop high-order thinking, and cultivate innovation ability. Against this background, exploring problem-design strategies that conform to the concept of the new curriculum standards, adapt to the cognitive characteristics of high - school students, and can effectively promote the construction of chemical models not only has theoretical innovation value but also helps to provide front-line teachers with operable teaching guidance, promoting the substantial implementation and deepening of chemical modeling teaching.

2. Theoretical Foundation and Real - world Reflection on Problem Design in Chemical Modeling Teaching

2.1. Theoretical Foundation

The effective strategies for problem design in chemical modeling teaching are not built on thin air but are deeply rooted in the solid soil of educational theories. Cognitive constructivism provides the core psychological basis for the problem-driven model construction process. Piaget's "cognitive conflict" theory states that learning occurs due to the imbalance between an individual's original cognitive structure and new information[1]. Well-designed problems can create appropriate cognitive conflicts, forcing students to face the limitations of their initial models and thus stimulating their internal motivation to actively adjust and reconstruct their cognitive structures, achieving an "accommodation" - type conceptual change.

Meanwhile, Vygotsky's "Zone of Proximal Development" (ZPD) theory emphasizes the importance of external guidance [2]. A series of "scaffolded" problems with gradients and logicality, just like the scaffolds provided by teachers or peers, can help students cross the area between their independent problem-solving level and the level they can reach with guidance, gradually completing the construction of complex scientific models.

The model theory in science education clarifies the teaching objectives and essence of chemical modeling. This theory holds that scientific models are not exact replicas of the objective world but "thinking tools" formed by scientists through simplification, abstraction, and idealization of complex realities for specific purposes [3]. Therefore, the fundamental purpose of chemical modeling teaching is not to let students memorize the final form of the model but to enable them to understand how the model is constructed, tested, revised, and applied, and to recognize the hypothetical, approximate, and variable nature of the model.

2.2. Real-world Reflection

Although the educational concept of chemical modeling has been widely accepted, its application in teaching practice, especially in the problem-design stage, still shows systematic deviations that are contrary to the essence of this concept. These deviations restrict the effective development of students' model - cognition literacy. By examining the current high - school chemistry teaching, the common defects in problem design can be summarized into three categories.

The widespread existence of verification - type problems. These problems require students to use the taught scientific models to explain specific phenomena[4]. For example, "Explain the V- shaped configuration of the water molecule based on the valence-shell electron - pair repulsion theory." In this mode, students' cognitive activities are limited to the repetition of existing knowledge and the application of ready-made rules, rather than experiencing the inquiry process of independently constructing and revising models from evidence. This design simplifies the dynamic inquiry process of modeling into a mechanical verification of static conclusions, deviating from the core goal of cultivating students' scientific inquiry ability.

Problem design often shows a fragmented logical characteristic. The question sequences in teaching often lack an internal progressive relationship and fail to form a coherent path to guide the development of students' thinking. For example, in the teaching of acid-base ionization, the questions may directly jump from the concept definition to the writing of chemical equations, ignoring the key links that can stimulate in-depth thinking, such as exploring "the reason for the significant difference in acidity between hydrochloric acid and acetic acid of the same concentration." This non-continuous questioning cannot support a complete modeling cognitive cycle, resulting in students only obtaining discrete knowledge points without constructing a thinking model with internal consistency and explanatory power[5].

Closed - ended questions dominate in teaching. Such questions aim to guide students to obtain a single, preset correct answer, such as directly asking "What is the spatial configuration of the methane molecule?" This way of questioning actually cancels the students' inquiry process and limits their possibility of proposing multiple hypotheses, conducting arguments, and making evaluations. In contrast, an effective modeling question should be open-ended. For example, "Based on the bonding principle of carbon atoms, speculate on the possible spatial structure of the methane molecule and demonstrate its stability." This provides the necessary space for students' independent inquiry and divergent thinking.

3. Construction and Connotation of the "P-C-R" Progressive Problem-Chain Design Strategy

3.1. Three-Stage Cyclical and Progressive Model of "Phenomenon-Driven, Conflict-Construction, Refinement-Iteration"

This paper constructs a progressive problem-chain design strategy called "Phenomenon-Driven, Conflict-Construction, Refinement-Iteration", abbreviated as "P-C-R". This strategy model structures the complex modeling teaching process into three interrelated, cyclical and progressive core stages.

The P (Phenomenon-Driven) stage is the starting point of modeling. By introducing a real, interesting or abnormal chemical phenomenon as an "anchor point", it stimulates students' inquiry interest and prompts them to form a preliminary and possibly imperfect "initial model" based on their existing experience.

The C (Conflict-Construction) stage is the key to thinking transformation. Through designing a series of "hinge questions", it creates cognitive conflicts between students' initial models and new evidence or logical deductions, enabling them to deeply recognize the limitations of the original models and thus generating an internal need to revise the models.

The R (Refinement-Iteration) stage is the core link of model development. Through a set of hierarchical "scaffold problem chains", it guides students to continuously revise, test, apply and generalize the models, making them gradually approach the scientific model and understand the applicable boundaries of the model.

3.2. P Stage (Phenomenon-Driven)-Anchoring and Triggering: Designing "Anchor Questions"

The P stage is the initial link of chemical modeling teaching, and its core goal is to anchor the inquiry starting point and trigger the learning motivation. The key to the success of this stage lies in designing high-quality "anchor questions".

"Anchor questions" stem from a chemical phenomenon that can arouse students' interest and curiosity. This phenomenon should have the following characteristics: authenticity, originating from real situations in daily life, industrial production or the history of science, avoiding emptiness and falsehood; singularity or complexity, that is, the phenomenon itself is beyond students' daily experience or intuitive expectations (abnormal phenomenon), or contains multiple variables and cannot be directly explained by simple existing knowledge.

By presenting such a phenomenon, the teacher poses an open - ended "anchor question", such as "Why does iron and steel rust in moist air but not easily in pure oxygen or pure water?" or "When KSCN solution is added to ferric chloride solution, the solution turns red. Then, when iron powder is added, the red color fades. Why?" The function of such questions is not to require students to give the correct answer immediately, but to guide them to mobilize their existing knowledge and experience to form a preliminary and personalized explanatory framework, that is, the "initial model". This initial model may be incomplete, inaccurate or even wrong, but this is the starting point of modeling. Therefore, the problem design in the P stage aims to transform students from passive knowledge receivers into active thinkers, laying the necessary emotional and cognitive foundation for subsequent cognitive conflicts and model construction.

3.3. C Stage (Conflict-Construction)-Exposure and Reconstruction: Designing "Hinge Questions"

The C stage is the most challenging and crucial part of the entire modeling process. Its core objective is to expose the limitations of the initial model and construct cognitive conflicts. In this stage, teachers need to carefully design "hinge questions", which act like the hinges of a door, serving as the turning point connecting students' old and new cognitions.

The function of hinge questions is to create strong cognitive conflicts by presenting new evidence, new situations that contradict the initial model students formed in the P stage, or by posing logical challenges. The design of such conflicts can be divided into three categories:

Model-evidence conflict: Provide experimental data or phenomena that do not match the predictions of students' models. For example, for an initial model that assumes “a reaction stops only when the reactants are exhausted”, present data showing that the concentrations of all substances remain constant when a reversible reaction reaches equilibrium.

Conflict between different models: Guide students to compare their models with those of others (or an alternative incorrect model provided by the teacher) to identify the deficiencies of their own models.

Internal logical conflict of the model: Lead students to deduce the inevitable conclusions of their models and discover internal contradictions.

An effective “hinge question” should be precise and subversive, enabling students to clearly realize that “my original idea might be wrong”. This will generate a strong, intrinsic desire to revise the model, preparing them mentally and intellectually for the subsequent refinement - iteration stage.

3.4. R Stage (Refinement-Iteration)-Iteration and Refinement: Designing the “Scaffolding Question Chain”

After students develop an internal drive to reconstruct the model, the core goal of the R stage is to provide cognitive scaffolding to guide the iteration and refinement of the model. Merely breaking the old model is not enough; students also need to be guided to build a new one.

In this stage, teachers should design a logically progressive and well-structured “scaffolding question chain”, which is like a scaffold to help students gradually reach higher levels of cognition. This question chain typically consists of the following four levels:

Revision-type questions: Directly prompt students to think about how to adjust the model to explain the conflicts that emerged in the C stage. For example, “Since the forward and reverse reactions occur simultaneously, what should the microscopic state of the’macro-static’ equilibrium state be?”

Verification-type questions: Encourage students to consider how to verify their newly revised models, either through real experiments or thought experiments. For instance, “Can you design an experiment (such as using isotope tracing) to prove that your proposed ‘dynamic equilibrium’ model is correct?”

Application-type questions: Require students to apply the newly constructed model to explain new phenomena or predict new results, thereby testing and consolidating the model’s explanatory and predictive power. For example, “Using your dynamic equilibrium model, predict the effect of increasing pressure on the ammonia synthesis reaction.”

Generalization-type questions: Guide students to explore the applicable boundaries and limitations of the model and consider whether it can be transferred to other contexts. For example, “Can the chemical equilibrium model we’ve established be used to explain the dissolution process of table salt?”

Through this series of closely-linked questions, students not only construct scientific models but, more importantly, experience the scientific process of continuous model improvement, and their model - thinking abilities are substantially enhanced.

4. Implementation Requirements and Development Paths of the “P-C-R” Strategy

4.1. Teachers’ Challenges and Empowerment: From “Designers” to “Guides”

The implementation of the “P-C-R” strategy requires teachers to transform their roles from knowledge “transmitters” to inquiry “designers” and “guides”. The core competence of teachers is no longer about explaining knowledge, but rather about designing high-quality question chains (anchor questions, hinge questions, and scaffolding questions) and guiding students’ independent inquiry. This demands that teachers possess the professional wisdom to accurately diagnose students’ prior concepts, skillfully create cognitive conflicts, and timely provide cognitive scaffolds. Therefore, teachers’ professional development should focus on systematically enhancing their question-design and classroom - guiding abilities through specialized teaching research and case studies, so as to empower them to handle student - centered modeling teaching.

4.2. Implications for Teaching Evaluation: Process - Oriented Evaluation Beyond Results

The implementation of the “P-C-R” strategy inevitably requires a shift in teaching evaluation from focusing on “results” to focusing on “processes”. The emphasis of evaluation should move from measuring whether students have mastered the final model to assessing their thinking performance during the modeling process, such as the ability to propose hypotheses, deal with conflicts, revise models, and conduct critical reflections. To this end, diverse formative evaluation methods such as classroom observation, inquiry journals, model explanations, and group defenses should be adopted to comprehensively and truthfully reflect and promote the development of students’ model - cognitive literacy.

4.3. In-Depth Integration with Modern Educational Technology: Empowering Strategy Implementation

Modern educational technology can greatly empower the implementation of the “P-C-R” strategy. Virtual simulation technology can present “anchor phenomena” and “conflict evidence” that traditional experiments cannot show. Data analysis tools can support students in quantitatively testing and revising models in the “R stage”. Moreover, artificial intelligence (AI) has the potential to intelligently diagnose students’ models and automatically generate personalized “hinge questions” and “scaffolding questions” in the future. The integration of technology can break through teaching bottlenecks, improve the efficiency and effectiveness of strategy implementation, and promote the development of chemical modeling teaching towards intelligence and personalization.

5. Conclusion

To truly realize the educational value of chemical modeling under the new curriculum standards, the key lies in a transformation of the teaching paradigm from “knowledge transmission” to “thinking construction”, and the pivot of this transformation is systematic problem design. Facing the common dilemmas in current teaching, such as verification-type, fragmented, and closed- ended problem designs, the “Phenomenon-Driven, Conflict-Construction, Refinement-Iteration” (P-C-R) progressive problem-chain strategy constructed in this paper provides front-line teachers with a clear and operable roadmap. The essence of this strategy is to simulate and accelerate the real process of scientific inquiry in the classroom through delicate logical arrangement. In the P stage, it uses real-life situations to spark students’ mental curiosity. In the C stage, it forces students to reflect on and subvert their existing knowledge through precise cognitive conflicts. Finally, in the R stage, it guides students to independently construct more refined and scientific thinking models through a series of progressive cognitive scaffolds.The goal is to lead students to go beyond memorizing chemical knowledge, truly experience the charm and power of scientific thinking, and transform them from passive consumers of knowledge into future explorers who can actively identify problems, construct meaning, and solve problems with innovative thinking.

Disclosure statement

The author declares no conflict of interest.

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