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Research on Improvement and Innovation Strategies for High School Chemistry Experiments

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Abstract: This research integrates analyses from the Guangdong Provincial Experiment Lesson Presentation Competition, Guangdong Provincial Chemistry Experiment Operation and Innovation Skills Competition, and case studies from our research group to explore experimental innovation as a means of fostering a scientific spirit in students. By transitioning from a competitor to a judge, the paper refines strategies for improving and innovating chemistry experiments to better cultivate students' core competencies in the subject.

Keywords: High School Chemistry; Experiment Improvement and Innovation; Core Competencies.

1. Introduction

The *General High School Chemistry Curriculum Standards (2020 Edition)* advocates for "creating authentic problem-solving scenarios, conducting various inquiry activities primarily through chemistry experiments, emphasizing structured content design to stimulate students' interest in chemistry, facilitating a shift in learning methods, and fostering their innovative spirit and practical skills" [1]. Against the backdrop of a competency-based curriculum reform, enhancing and innovating chemistry experiments is crucial for developing students' innovative thinking and core competencies. Such improvements are pivotal in strengthening basic education's capacity for innovation and contributing to the development of a technologically advanced nation.

A search within the *China National Knowledge Infrastructure* (CNKI) database using the terms "experiment improvement," "experiment innovation," and "high school chemistry" reveals that research on chemistry experiment innovation, particularly at the high school level, is less prevalent than in other subjects. Furthermore, there are fewer studies focusing on teaching strategies for high school chemistry experiments. Although there is theoretical and practical research related to the subject, practical studies are noticeably lacking in terms of quantity and scope.

Table 1. shows a comparison of the number of papers published on "Experiment Improvement" and "Experiment Innovation" over the last five years.

Year / Amount / Keywords	2020	2021	2022	2023	2024	Total
Experiment Improvement or Experiment Innovation	1190	1033	992	1126	609	4950
Experiment Improvement or Experiment Innovation; High School Chemistry	27	19	32	25	3	106
Experiment Improvement or Experiment Innovation; High School Chemistry; Strategies	0	0	0	1	0	1

Consequently, this paper uses the example of high school organic chemistry experiments to analyze cases from the Guangdong Provincial Experiment Lesson Presentation Competition, Guangdong Provincial Chemistry Experiment Operation and Innovation Skills Competition, and our research group's case studies. From participant to judge, and ultimately to teaching practice, it distills implementation strategies for experiment innovation to enhance students' core competencies in chemistry.

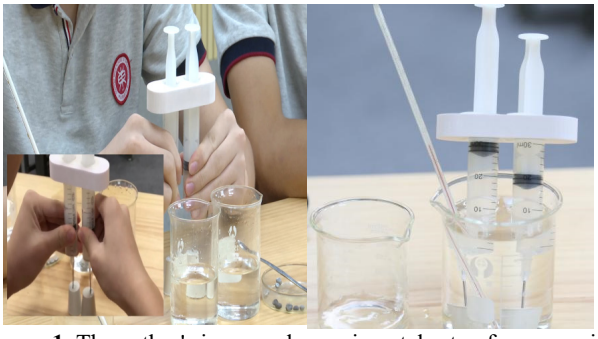


Figure 1. The author's improved experimental setup for measuring the reaction rate between zinc and dilute sulfuric acid

2. Principles for Experiment Improvement and Innovation

Based on extensive practical experience, ensuring the quality of high school chemistry experiment improvement and innovation requires adherence to specific principles:

First, Scientificity. During the improvement and innovation process, some teachers focus excessively on the novelty of the experiment design, neglecting potential scientific issues. Scientificity includes the scientific basis of the experiment, the standardization of equipment, the accuracy of operations, and the stability of results. This principle is fundamental to ensuring the reliability of innovative experiments. It is crucial to repeatedly test new experimental schemes and verify their effectiveness to ensure that the phenomena can be consistently reproduced [2].

Second, Intuitiveness. A key objective in improving chemistry experiments is to make the phenomena more intuitive and noticeable. This includes making subtle reactions clearly visible, slowing down fast reactions to extend observation time, shifting from qualitative to quantitative visibility, and transforming abstract concepts into visual representations. This principle marks a successful experiment improvement. Based on this principle, teachers and students can modify experimental setups, adjust the quantity of reagents, and utilize digital equipment to ensure all students can clearly observe the phenomena, facilitating the drawing of accurate conclusions.

Third, Simplicity. As a judge in the Zhongshan City Experiment Operation and Skills Competition, I observed that some innovative experiments became overly complex, losing their intended purpose. Improvements should be simple and easy to operate, maintaining scientific accuracy. This facilitates replication in other classrooms, avoids overly complicated procedures that can distract students, occupy too much class time, or lead to experimental failure, thus enhancing the efficiency of experiment improvement and saving learning time.

Fourth, Safety. Safety is always paramount. Any safety accident, minor or severe, can lead to disqualification from competitions or injury to students or teachers. When improving experiments, teachers need to carefully consider and eliminate potential safety risks and develop more standardized and rigorous experimental procedures. Before group experiments, teachers should also proactively explain practical and valuable accident handling methods to students.

During my improvement of the reaction rate experiment between zinc and dilute sulfuric acid (from the old People's Education Press textbook), I adhered to these four principles, simplifying the main apparatus to two syringes fixed on a PVC board, making the experiment equipment easily accessible, cost-effective, simple to operate, and highly effective. Despite the simplicity of the principle, this experiment won me first place in the Guangdong Provincial Chemistry Experiment Lesson Presentation Competition that year [3].

3. Designing Experiments Based on Real-World Problem Solving for Deep Learning

For high school students with a basic foundation in chemistry, designing experiments based on real-world problems is an effective way to cultivate higher-order thinking and embodies the scientific spirit of seeking truth and fostering innovation. The new curriculum standards encourage setting real-world contexts and tasks to transition from knowledge-based to competency-based learning. The experimental improvement cases developed by the research group I lead, titled *Research on Implementation Strategies of Micro-Projects in New Organic Chemistry Textbook Based on Deep Learning* (referred to as the Provincial Research Group), are primarily designed based on real-world problem-solving to achieve deep learning. For example, in the award-winning micro-lesson on acetic acid, I set up real-life scenarios like cooking fish with vinegar or dealing with fish bones stuck in the throat to pose questions, set experimental tasks, and ultimately deepen understanding while solving real-life mysteries, impressing students, transforming rote memorization into deep understanding, and effortlessly mastering knowledge while enhancing students' core competencies and fostering their scientific spirit.



Figure 2. Experiment of fish bones soaked in anhydrous acetic acid for 24 hours: The fish bones did not completely dissolve after soaking in anhydrous acetic acid for 24 hours, indicating that vinegar cannot resolve the issue of large fish bones stuck in the throat

4. Assigning Diverse Experimental Innovation Tasks to Students

Innovation in experiments should not solely involve teachers; it is crucial to encourage students to innovate independently. Beyond routine written assignments, assigning a variety of innovative experimental tasks can significantly enhance students' exploratory interests and unlock their creative potential. This includes at-home or extracurricular experiments, such as making homemade rice wine during lessons on ethanol, soaking eggshells in vinegar during lessons on acetic acid, encouraging students to explore the principles behind self-heating rice meal packs during lessons on chemical and thermal energy, or encouraging students to implement metal corrosion protection measures. These experiments are characterized by enhancing students' practical skills, closely relating to everyday life, utilizing multidisciplinary knowledge to solve practical problems, and fostering high-order thinking. Experimental supplies and equipment are easily accessible, and the designs are simple and clear, enabling students to complete these tasks [4].



Figure 3. Student-made rice wine

5. Mastering Digital Experimentation for Iterative Innovation

Taking Lin Xiaoxia's development of the "Ethanol and Sodium Reaction" experiment from the Provincial Research Group as an example [5], this case provides a model for how to progressively refine experiment innovations from simple, easy-to-adopt procedures to complex challenges using digital technology for quantitative analysis. This experiment won first place in the 2021 Guangdong Provincial Middle and Primary School Experiment Teaching Lesson Presentation Competition, was selected as a provincial-level excellent course in the 2021 Guangdong Provincial Middle and Primary School Experiment Excellent Course Selection Activity, and was featured as a "Discussion Class Example" in the 14th National Primary and Secondary School Students' Innovative Classroom Teaching Practice Observation Activity.

The "Ethanol and Sodium Reaction" experiment is a compulsory experiment in the current high school chemistry curriculum. This experiment aims to demonstrate that the reaction between ethanol and sodium produces hydrogen gas, thus confirming the presence of hydroxyl groups in ethanol and helping students understand the concept of functional groups in organic compounds, which are crucial in determining their chemical properties.

To address some of the issues in traditional experiments and explore the potential for transforming demonstration experiments into student experiments, Teacher Lin used readily available equipment, such as syringes and infusion tubes, to assemble a low-cost, simple-to-make integrated setup for preparing, collecting, purifying, and testing gases without heating.

This approach was further extended to other solid-liquid non-heating reactions for producing common gases like hydrogen and carbon dioxide.

Further application to the preparation and properties of organic gases, such as "The Preparation and Combustion of Acetylene." The improved method eliminates the need for saturated salt water, reducing students' difficulty in understanding chemical equations; also, the experimental process does not release any polluting or irritating gases, ensuring safety and environmental protection.

Further expanded to experiments revealing the principles of chemical reactions, such as "Exploring the Effect of Concentration on Reaction Rate." The improvement reduces the amount of reagents needed, simplifies operations, makes experimental phenomena more apparent, enables group experiments by students, saves teaching time, and transitions from qualitative to quantitative exploration, fully leveraging the teaching function of the experiment.

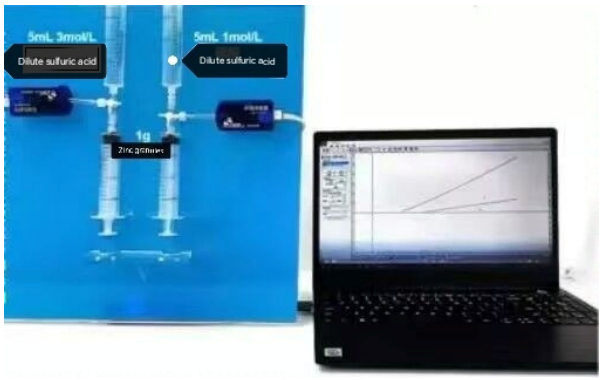


Figure 4. Innovative Setup for Quantitative Gas Production

Experimental teaching is a major highlight of chemistry education. Applying improvements and innovations to experimental teaching can greatly enhance students' interest in the subject, thereby improving teaching effectiveness and cultivating their scientific spirit. It is crucial to encourage teachers to innovate and students to engage in hands-on experiments and thoughtful reasoning, to maximize the development of their potential as scientists.

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