Bringing Virtual Simulation Experiments into the Secondary School Chemistry Class

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Abstract. Chemistry is an empirical discipline that relies on experiments to verify its theories and laws. Therefore, chemistry teachers should not only impart factual knowledge of chemical concepts and principles to students, but also demonstrate how these concepts and principles were derived through experimental methods [1]. However, conducting real experiments in high school poses significant challenges due to students' lack of safety awareness and the constraints of funding and space for laboratory facilities. This paper suggests that virtual simulation experiments can be integrated into chemistry teaching as an alternative solution. The benefits of virtual simulation experiments include: (1) high safety; (2) high success rate; (3) effective pedagogical outcomes; (4) environmental friendliness; (5) strong feasibility; and (6) advanced technology.

Keywords: chemistry teaching · high school · virtual simulation experiment

1 Introduction

Numerous studies have explored the use of virtual labs in college teaching since the twentieth century. Virtual simulation experiments can enhance students' self-directed learning skills and enable teachers to manage multiple classes more efficiently. This paper proposes to apply the virtual simulation experiment system to high school chemistry teaching as a potential solution for some of the challenges faced by chemistry education at this level. Chemistry is a fundamental natural science that investigates the composition, properties, structure and laws of change of substances and their applications at the atomic and molecular levels [2]. However, in many Chinese high schools, students study for "exams" rather than for understanding, and teachers emphasize theoretical knowledge over practical skills. In contrast, university education aims to develop students' scientific thinking and experimental abilities to meet the demands of social production and technological advancement. This discrepancy leads to difficulties for students who transition from high school to university education. Some students report unsatisfactory learning outcomes. Therefore, this paper suggests that virtual simulation experiments should be introduced more extensively in high school chemistry education as a low-cost and feasible model that can improve experimental teaching quality.

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2 The Necessity of Strengthening Experimental Education at the High School Level

The proportion of laboratory-based courses in college has experienced a notable increase in comparison to high school education. For students pursuing a major in chemistry, a mandatory four-year experimental curriculum is implemented, commencing in their freshman year, in addition to comprehensive and innovative experimental design courses. It is evident that students are expected to possess a diverse range of experimental skills. Hence, freshmen who possess a solid foundation in laboratory techniques may find it advantageous in facilitating their transition to college coursework.

3 The Introduction of Virtual Simulation Experiment Teaching in High School

Due to the significant academic workload and time constraints in high school, students' abilities across various domains may not have reached full maturity. As a result, it may not be practical for schools to construct multiple laboratories and administer authentic chemical experiments, given the potential safety hazards. In light of this, this paper advocates for the increased incorporation of virtual simulation experiments in high school classrooms.

3.1 Advantages of Virtual Simulation Experiments

Virtual simulation experiments utilize multimedia computer technology to construct experimental environments, comprising laboratories, instrumentation, and reagents, and subsequently establish experimental models that collect and analyze experimental data via network connections [3]. Drawing from personal learning experiences, this paper contends that virtual simulation experiments offer several advantages.

Firstly, Chemical experiments sometimes involve flammable and explosive materials, as well as toxic and hazardous reagents, which inherently pose a certain level of risk. Some experiments require high temperature and high pressure conditions, and operational errors can also potentially threaten personnel safety. Some high school students may have a weak safety awareness and insufficient understanding of the hazards associated with experiments. They may focus solely on how to successfully complete the experiment, while neglecting safety precautions, resulting in safety hazards and even accidents. However, virtual simulation experiments can maximize student safety.

Secondly, virtual simulation experiments to some extent avoid the influence of the success rate of the experiment because of manual operation. In real experiments, slight operational errors may lead to unsatisfactory experimental results, and unavoidable manual operation errors can occur. Virtual simulation experiments have significantly improved the success rate of the experiment.

Thirdly, virtual simulation experiments improve the learning effect. Some experiments are difficult to observe, especially those with long durations or subtle color changes. Virtual experiments ensure the accuracy of the experimental results and help

students better observe the experimental process and products, allowing them to focus more on the results and analysis of the experiment itself [4].

Fourthly, virtual simulation experiments are environmentally friendly. Chemical experimental products may harm the environment, and controlling drug dosages is challenging in real experiments, resulting in the need to repeat experiments and consume more reagents. Virtual simulation experiments can avoid these problems and achieve green and environmental protection.

Fifthly, virtual simulation experiments improve the feasibility of experiments. The establishment of sufficient laboratories requires adequate funds and site support, which is difficult to achieve in many middle schools, especially in economically disadvantaged areas. Virtual experiments only require computer rooms, which are available in most middle schools.

Sixthly, virtual simulation experiments improve the advancement of teaching contents. Bring advanced experimental contents into the classroom is a challenge for educators, and the virtual simulation laboratory can use computer technology to enhance and improve the advancement and precision of experimental instruments [5].

Seventhly, it is conducive to teachers' grasp of students' learning outcomes. The virtual simulation experiment system adopts a "front-end + back-end" operating mode, where the front-end is the simulation interface and the back-end is the data monitoring system [6]. The data monitoring and analysis program primarily serves as an experimental instructor, and monitors and records the entire process and related data of all experimental participants (i.e. students) during the experiment, including the duration of each experimental step and error rate. The system's back-end integrates and analyzes the data, providing module scores (step scores) and final grades for each participant, which are synchronized to the teacher's side. Teachers can develop teaching plans based on the above data to understand students' completion status and learning outcomes.

Finally, virtual simulation experiments improve the progressiveness of teaching content. Many teachers have difficulty introducing advanced experimental content into the class, but virtual simulation laboratories can help them use computer technology to enhance the progressiveness and accuracy of experimental instruments.

3.2 The Effect of Virtual Simulation Experiment in Practice

Chattavut Peechapol from Southeast Asia University pointed out that many students find chemistry difficult to understand, complex, and abstract, requiring effort to comprehend. The difficulty of learning chemistry can be summarized by two reasons: firstly, the inherent nature of science makes it difficult to reach, and secondly, the limitations of traditional teaching methods. In order to improve this situation and find more effective teaching approaches than traditional teaching, Chattavut Peechapol explored the impact of virtual simulation experiments on students' learning outcomes, self-efficacy, and learning experience (Fig. 1). He conducted a study on 95 first-year undergraduate students majoring in chemistry, who were divided into a control group ($N = 45$) and an experimental group ($N = 50$). In addition to the 3-h traditional lecture-based learning experience, the experimental group also underwent a 1.5-h learning session on the same topic using virtual simulation experiments. Finally, the study tested all participants' knowledge mastery levels and self-efficacy, and statistically analyzed and compared the

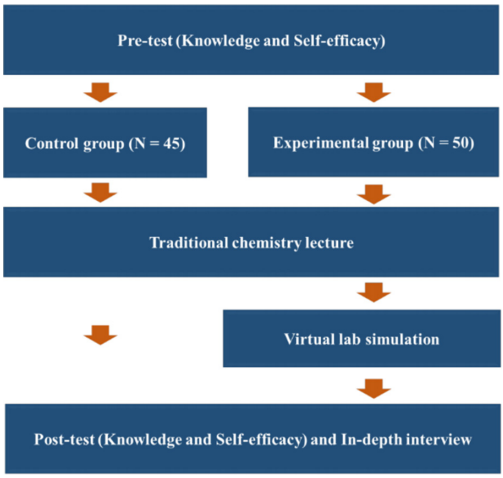

Fig. 1. The flow chart of this study [7]

scores, measuring students' understanding of specific concepts in chemistry and their ability to conduct experiments successfully. In addition, in-depth interviews were conducted to inquire about students' learning experiences participating in virtual simulation experiments, to obtain more information on the learning effects of virtual simulation experiments [7].

The results of this study (Fig. 2) indicate that for academic performance and self-efficacy, the experimental group of students had significantly higher scores in knowledge mastery and self-efficacy compared to the control group. This suggests that after traditional teaching, virtual simulation experiments have a significant enhancing effect on learning outcomes. From this, we can infer that Virtual Simulation Experiment helps students better understand and remember relevant chemical concepts, providing students with a more comprehensive and complete understanding of chemistry, rather than just staying at the theoretical level of textbooks. At the same time, it can subtly cultivate students' experimental skills and scientific literacy. Regarding learning experience, participating in virtual simulation experiments has a positive effect on students' learning experience in chemistry, which can be summarized as follows: 1) stimulating students' interest in learning; 2) visualization and practice facilitating students' understanding of chemical concepts; 3) providing students with opportunities to repeat experiments as many times as they want.

While the aforementioned study focused on first-year university students, it holds important implications for high school education as well. High school is a crucial period of learning where students need to explore their interests in various subjects and identify their strengths in learning. Typically, high school students evaluate their perspectives and attitudes towards a subject based on two factors: "Am I interested in this subject?" and "How well am I performing in this subject?" Therefore, it is crucial to employ a more scientific and comprehensive approach to teaching chemistry to help students understand and learn the subject better, and to obtain more accurate answers to the two

Measure	Phase	Experimental group			Control group
		$\bar{x}$ ±SD			$\bar{x}$ ±SD
		Low knowledge	*High knowledge*	*Total*	
Knowledge level	Pre-test	4.80±1.71	8.93±0.88	6.04±2.43	6.27±1.79
	Post-test	10.97±1.36	13.87±0.64	11.84±1.79	9.24±1.76
Self-efficacy	Pre-test	2.82±0.59	3.63±0.40	3.07±0.66	3.11±0.54
	Post-test	3.84±0.48	4.46±0.21	4.03±0.50	3.70±0.59

Fig. 2. The result of this study [7]

aforementioned questions. In this regard, virtual simulation experiments can serve as an effective tool.

4 Steps of Conducting Virtual Simulation Experiments

The author utilized simulation software to perform a virtual simulation experiment titled "determination of elemental Ca" using the Beijing Oriental simulation software system, which was developed based on the Shimadzu atomic absorption spectrophotometer, in college. Drawing on this experience, the present study puts forth the following recommendations for the teaching steps involved in virtual simulation experiments (Fig. 3):

Firstly, watching the training videos of the simulation system enables teachers to provide further explanations based on practical situations, which helps students to gain a better understanding of the experimental principles. Secondly, students can practice independently by focusing on the modules they have questions on from the previous step, or by completing the entire experimental operation to ensure proficiency during the formal experiment. Thirdly, students perform the formal experiment. Fourthly, the system retains the students' operation data, automatically grades and synchronizes it with the teacher (Figs. 4 and 5).

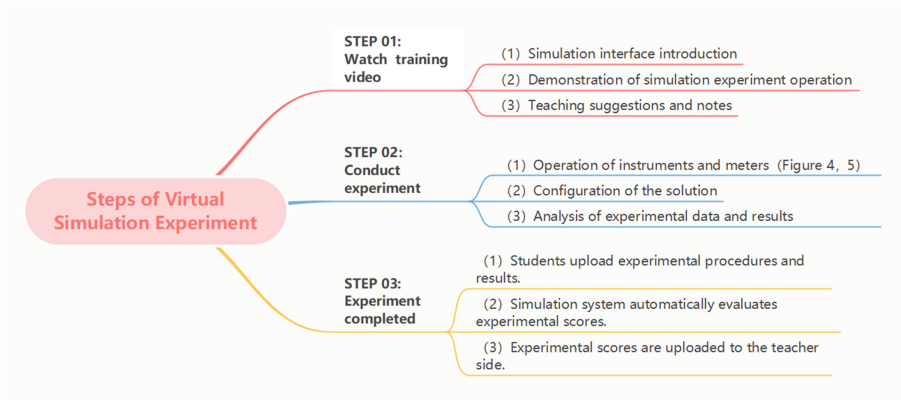

Fig. 3. Steps of virtual simulation experiment

Fig. 4. Simulation operation demonstration screen in the training video

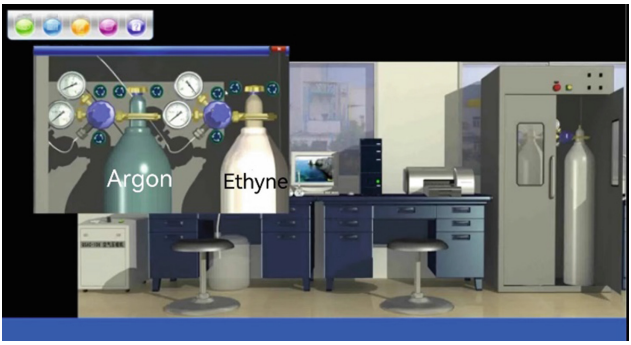

Fig. 5. Simulation operation demonstration screen in the training video

5 Conclusion

Virtual simulation experiments represent a novel experimental pedagogy that offers a wide range of comprehensive experimental instruments with clear and concise operation interfaces. Through interactive computer-based platforms, students can experience simulated experimental environments that mimic real-life scenarios. While chemistry education traditionally starts with theoretical knowledge, it ultimately necessitates practical application in production and daily life. As such, it is essential for high school students to gain an understanding of experimentation and the practical application of theoretical concepts. In light of external constraints, virtual laboratory teaching presents a valuable option for most high schools.

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