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Research Article

Teaching Design for Practical Courses Based on Virtual Simulation Technology

Zhang Liqiu[1], Wang Qining[2], Liu Lichun[1], Ai Ning[1, 2, *]

[1]College of Biological, Chemical Science and Engineering, Jiaxing University, Jiaxing, China

[2]National Virtual Simulation Experiment Teaching Center for Experimental Chemistry and Chemical Engineering Education, Zhejiang University of Technology, Hangzhou, China

Abstract

The National Virtual Simulation Experimental Teaching Project (NVSETP) is one of the five "Golden Courses" launched by the Ministry of Education (MoE) of the People's Republic of China. These courses need to adhere to the Golden Course standards, which include offering a curriculum that is innovative, challenging, and designed to develop higher-order thinking skills through rich content and novel teaching methods. Students receive opportunities for both practical and theoretical learning that guide them in engaging in innovative thinking and practice. This article discusses the teaching design for practical courses based on Virtual Simulation Technology, grounded in the Outcome Based Education, and drawing from the construction of the first batch of NVSETP Teaching Centers and Projects. It primarily addresses four aspects of teaching: objectives, curriculum content, methods, and assessment. Taking the lack of real experimental engineering conditions and high-risk, high-cost practical operations as the starting point, this paper designs the teaching content and methods; Revising the traditional experimental teaching process, this paper adopt blended learning methods. Evaluates the learning effect of students through the real-time feedback of virtual simulation software, further reforms the teaching and improves the teaching effect. The paper provides a reference for constructing Virtual Simulation Experimental Teaching Projects and reforming practical course teaching.

Keywords

Virtual Simulation, Practical Courses, Teaching Design, Output-Oriented

1. Introduction

Virtual Simulation Experiments (VSEs) utilize networked, digital, and intelligent technologies such as multimedia, big data, 3D modeling, artificial intelligence, human-computer interaction, sensors, supercomputing, virtual reality, augmented reality, and cloud computing to generate virtual systems that simulate real experimental systems. They have applications in various disciplines, such as chemistry, linguistics, medicine, and transportation science [1-4]. In chemistry practice classes, this allows students to interact and operate in a realistic environment, which can help them achieve experimental research purposes such as verifying theories, exploring rules, or establishing hypotheses. VSEs promote the deep integration of modern information technology and experimental teaching projects, expanding the

*Corresponding author: ain-ing@tsinghua.org.cn (Ai Ning)

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breadth and depth of content, extending the time and space of instruction, and significantly improving the quality and level of experimental teaching.

VSEs are significant to educational informatization and experimental teaching reform. The MoE in China recognized 305 national level Virtual Simulation Experiment Teaching Centers from 2013 to 2015. In 2017, it also launched the National Virtual Simulation Experimental Teaching Projects (NVSETPs) recognition work [5, 6], recognizing 1034 national level Virtual Simulation Experiment Projects [7, 8]. VSEs are also listed as one of the five types of "Golden Courses". In June 2018, the MoE in China put forward the concept of "Golden courses" for the first time. In order to effectively improve the quality of the course teaching and create some high-quality courses with difficulty and depth, namely the so-called "Golden course". "Golden courses" emphasize students' active participation and the cultivation of practical ability. Teachers should use group discussion, case analysis, field investigation, and other teaching methods to engage students in hands-on activities, experiential learning, and interactive tasks, thereby cultivating their innovative thinking and practical skills.

Scholars conducting research in higher education management, laboratory construction, and experimental teaching have studied VSEs in depth. For instance, Li Ping [9-11] summarized the identification situation of National Virtual Simulation Experiment Teaching Centers over the recent years, while Wang Xiaodi [12] and others discussed the eight types of relationships involved in constructing these centers. For instance, the relationship between Virtual Simulation Experiment Teaching and Educational Informatization; the relationship between Virtual Simulation Experimental Teaching Center and Experimental Teaching Demonstration Center; the relationship between virtual simulation experiment and real experiment, etc. Xiong Hongqi [13] summarized the eight new-era teaching characteristics of NVSETPs. For instance, wonderful experimental content; clever experimental conception; advanced experimental techniques; flexible experimental practices, etc. Research has also focused on the role of VSEs in teaching. For instance, in her work on using VS as a tool in teaching healthcare learners, Margaret Verkuyl outlined ten tips for effectively integrating virtual simulation into the curriculum [14]. Liu Yafeng et al. [15] explored the teaching plan design of VSEs, while Li Zhenbiao [16] explored the drawbacks that software for VSEs should address and avoid.

As one of the five types of Golden Courses launched by the MoE, the NVSETP should reflect two properties (higher-order and innovation) and one degree (challenge), and a teaching design guided by student learning output is the key to achieving these standards [17, 18]. The MoE also explicitly requires this experimental teaching design for NVSETP to be original. However, existing literature on this topic is still not sufficiently systematic, which to some extent affects project construction and application effectiveness. Thus, starting from the construction of the first batch of National Virtual Simulation Experimental Teaching Centers and NVSETPs, this article explores the teaching design of practical courses based on Virtual Simulation Technology. It examines teaching objectives, content, methods, and assessment and evaluation methods to provide guidance for the construction and application of VSETPs.

2. Curriculum Teaching Design Under the OBE Education Model

The Outcome Based Education (OBE) model first emerged during the 1990s education reforms in the United States and Australia. It is recognized as an effective method for pursuing excellence in education and received attention from universities around the world, becoming an important concept for improving the quality of professional education in Chinese universities. The OBE system is shown in Figure 1.

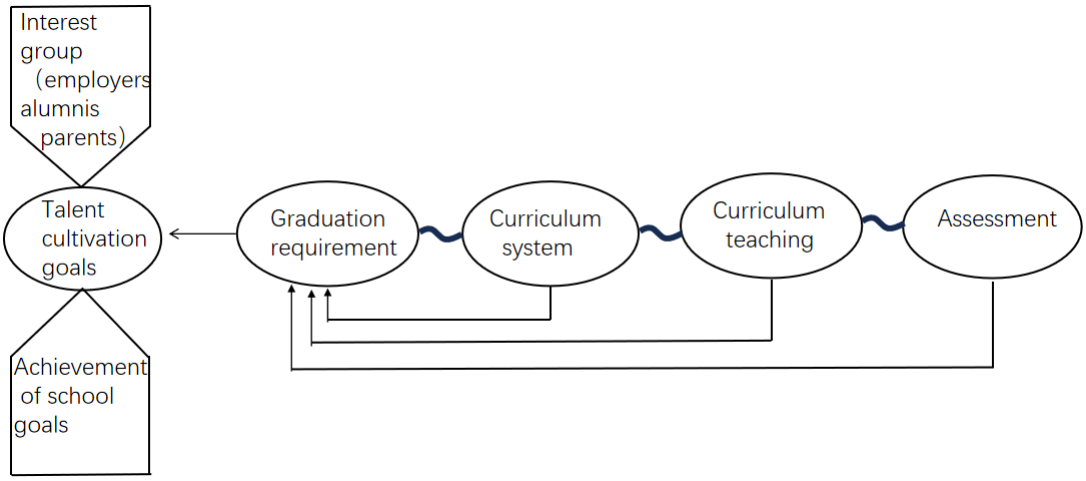


Figure 1. *OBE system.*

The university major developed following the OBE model should first determine their major's talent which are an overall description of the career and professional achievements that graduates can achieve approximately five years after graduation. The goals should be based on the interests of the stakeholders such as employers, alumni, teachers, parents, and students, and the school. To achieve these talent cultivation goals, students are required to attain certain abilities prior to graduation. In order to achieve these graduation requirements, the major must offer a suitable curriculum system which can support the graduation requirement. This support must be measured and validated through appropriate student assessment and course evaluation.

In OBE, the goal of teaching design and implementation is for students to achieve learning outcomes through the educational process. Teaching design broadly refers to the process in which teaching methods, content, and materials are adjusted based on the requirements of curriculum standards and student characteristics. Specifically, it involves developing appropriate teaching plans, through the creation of teaching objectives, establishment of tasks, time allocation for activities, and identification of teaching difficulties and methods. Teaching design is aimed at improving teaching efficiency and quality, enabling students to acquire more knowledge within a given time, significantly enhancing their abilities in all aspects, and thus supporting their overall development. The teaching design process for practical courses is shown in Figure 2.

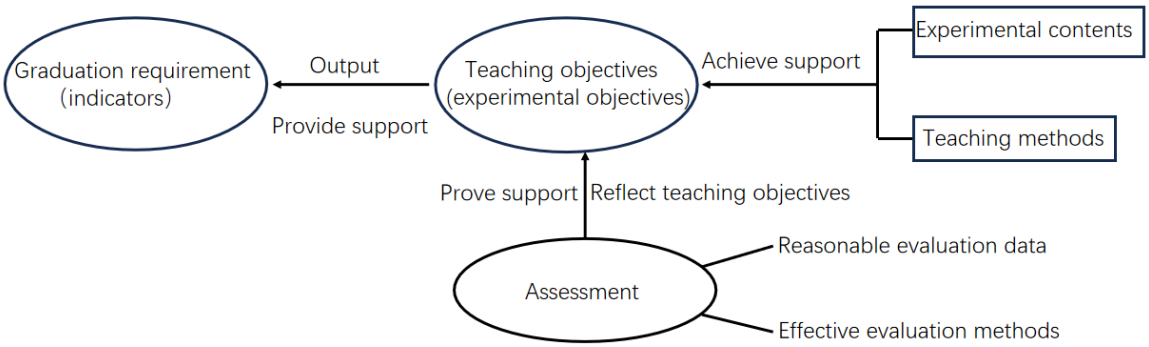


Figure 2. *Diagram of Teaching Design for Practical Activities.*

The model reflects the development of teaching (or experimental) objectives based on the graduation requirements and course or experiment indicators. The experimental content, teaching method, and forms of assessment should be selected based on teaching objectives. The achievement of teaching objectives must be demonstrated through carefully selected and effective evaluation and assessment methods and evaluation data. By utilizing virtual simulation technology, this teaching design will be more effective.

3. Design of Teaching Objectives

A course offered as part of the Virtual Simulation Experiment Teaching Project should adhere to a student-centered experimental teaching concept. This means it should be grounded in the needs of students, focusing on the comprehensive cultivation of their sense of social responsibility, innovative spirit, and practical ability. Emphasis should be placed on the collaborative implementation of knowledge transmission, ability cultivation, and quality improvement. Additionally, it should enhance the motivation and initiative of students to participate in experimental teaching, stimulate their interest and potential for learning, and enhance their innovative and creative abilities.

Virtual Simulation Experiments (VSEs) can be supported in certain areas of the engineering education professional certification curriculum, which supports the achievement of its graduation requirements (engineering knowledge, problem analysis, solution design/development, research, use of modern tools, engineering and society, environment and sustainable development, professional norms, individual work and teamwork, communication, project management, lifelong learning). Specifically, experimental data processing can strongly support the cultivation of problem analysis abilities. Optimizing experimental arrangements and providing in-depth explanations of results can strongly support the cultivation of research skills, while completing experiments in groups can effectively support independent learning and teamwork. Moreover, written and oral reports strongly support the cultivation of communication skills. Finally, exploratory activities and experimental thinking questions facilitate the development of lifelong learning abilities.

Another example is the first NVSETPs occurred in the field of chemical and pharmaceutical industries, as part of the Comprehensive Simulation Internship Project for Synthetic Ammonia Production. Four teaching (experimental) objectives were established across three dimensions: knowledge,

ability, and quality.

Objective 1: Through practical operations, students will master the basic principles of the synthetic ammonia production process, understand the principles and operation methods of typical unit equipment, learn about the automatic control principles and methods in continuous chemical production, and gain knowledge on starting, stopping, and fault diagnosis of chemical production equipment.

Objective 2: Through process simulation optimization, students will master analysis and synthesis methods of chemical systems.

Objective 3: Through comprehensive training, students will enhance their ability to identify, propose, analyze, and solve complex engineering problems, thereby meeting the relevant graduation requirements for engineering education certification;

Objective 4: To cultivate lifelong learning abilities and professional identity, students will engage in expanding their knowledge of projects and background information. Additionally, the curriculum will incorporate and ideological and political education to enable students to grow into qualified builders and future leaders in China's chemical industry.

4. Curriculum Content Design

The MoE emphasizes that Virtual Simulation Experimental Teaching Projects (VSETPs) should adhere to a problem-oriented approach, focusing on addressing issues such as the lack of real experimental project conditions or actual operational difficulties, involving high-risk or extreme environments, high costs, high consumption, irreversible operations. Such projects should also follow a demand-oriented approach, closely aligning with the needs of economic and social development for talent cultivation in universities, ensuring accuracy, concise content, reasonable duration, and appropriate difficulty. These requirements suggest the need for appropriate topic selection and content.

The construction of VSETP course begins with topic selection, and getting the right start is crucial for success. During the rapid development of VSETPs, the enthusiasm of universities and teachers to participate in this project is high, but some problems arose in relation to selecting topics. Firstly, there was a notable tendency towards homogenization. In 2018, a total of 35 chemical projects applied for NVSETPs, of which five were related to experimental safety topics. Finally, the interactive VSETP for chemical experimental safety education, led by Professor Chen Mingli from Northeastern University, was recognized as a national-level project. In 2019, a total of 84 chemical projects applied for NVSETPs, with seven focusing on safety in chemical laboratories. Some projects did not exceed the depth and breadth of the previously recognized projects in 2018, even remaining focused on the safety issues of a chemical reaction and the use of a common fire extinguishing equipment. The necessity of constructing more Virtual Simulation Experiment Teaching Projects course becomes questionable when similar projects are submitted. Secondly, there was a prominent trend towards scientific research. Some teachers developed their research projects into VSETPs for project innovation. Although their themes may have been novel, they often focused solely on the project itself, neglecting the key teaching points, which could affect students' grasp and in-depth exploration of the topic and negatively affect teaching effectiveness and benefits. Thirdly, some projects did not align with talent cultivation goals. Due to limited development capabilities, university teachers tend to collaborate with enterprises to apply NVSETP, often limited by the mature software already developed by the enterprise. For example, a certain Double First Class university applied for an NVSETP with the topic of on-site operation in a specific section, which deviated somewhat from its talent training goals. The Virtual Simulation Experiment Teaching Innovation Alliance now organizes and compiles the project construction guide by subject group, so related issues have improved, but they still require urgent attention.

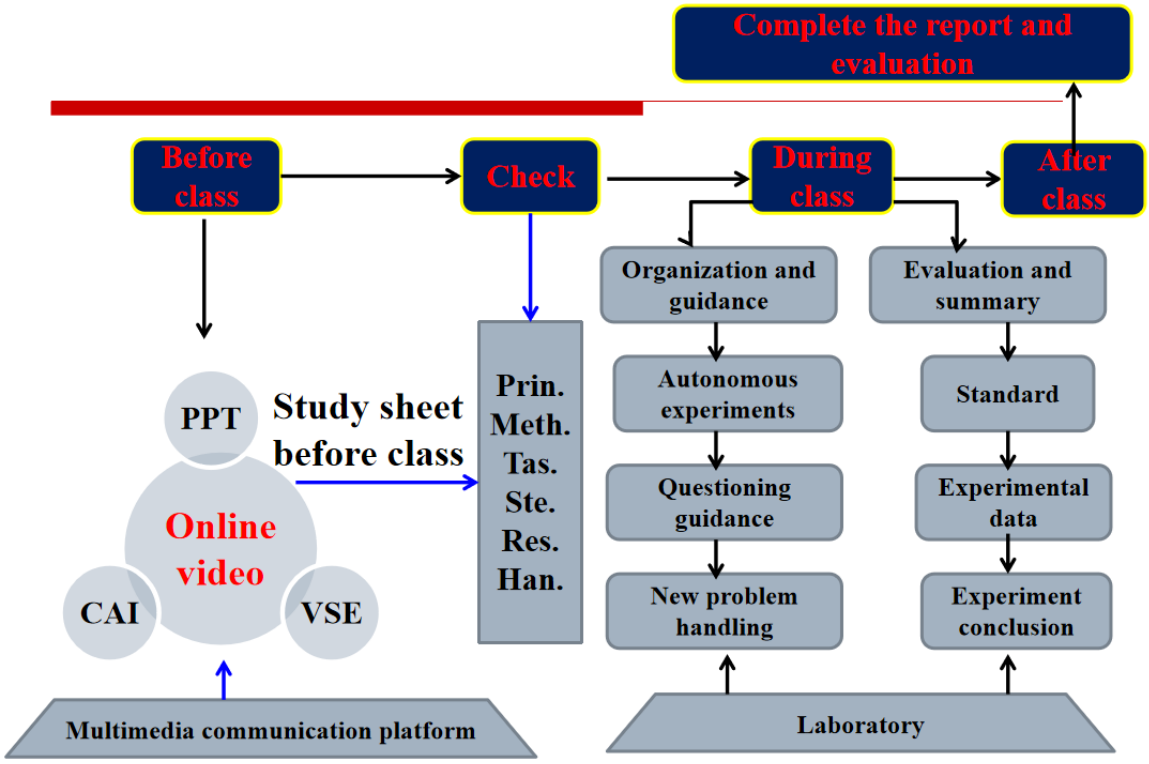
In terms of project content, the NVSETP should meet the experimental teaching needs of students within 2 class hours. The interactive experimental operation steps that students participate in must be no less than 10 steps. However, two erroneous tendencies have emerged: 1) some projects add too much complex content in order to appear substantial, diluting the core content; and 2) others have too many complex steps, while lacking interactivity and adding trivial steps, such as recording login interface and entering account and password. The content and steps of these projects should be moderate, focusing on what most requires virtual simulation. At the same time, the experimental operation steps are straightforward, with students following instructions step by step, which makes it difficult to leave a deep impression on them. Given the safety and low cost of virtual simulation experiments, the experimental steps can framed as "tasks", providing students with more room for independent thinking. Teachers can also introduce artificially set "faults" to enhance their ability to solve complex problems while eliminating them.

5. Design of Teaching Methods

The Virtual Simulation Experimental Teaching Project should address the needs of students in the information age, focusing on implementing interactive, seminar-based teaching methods that will occasionally engage with technology to solve problems and examine cases. It should advocate for autonomous, cooperative, and exploratory learning. Some educators have unclear understanding of teaching methods, listing four or five teaching methods in a project. Others overly emphasize the combination of virtual and real elements in their applications, leading to a strong dependence on physical devices, which greatly limits access for off-campus learners.

Traditionally, the experimental teaching process involves students previewing experiments based on a textbook, teach-

ers explaining the experimental principles and operations at the beginning of class, students conducting the experiment and completing reports, and teachers evaluating their performance. With VSETPs, the experimental teaching process can be reconstructed. For example, by adopting a hybrid teaching method and using a network platform, teachers and students can complete corresponding tasks before, during, and after class, as shown in Figure 3. For students with learning conditions, a learning mode combining online/offline tasks and real/virtual experiments can be adopted.



CAI: Computer-Assisted Instruction; VSE: Virtual Simulation Experiment
Prin. : principle; Meth. : method; Tas. : task; Ste. : step; Res. : result; Han. handle

Figure 3. *A Schematic diagram of the hybrid teaching mode.*

6. Design of Assessment and Evaluation Methods

Under the Outcome Based Education (OBE) model, student assessment and course evaluation are crucial for assessing student learning outcomes and continuously improving the teaching process. In traditional experiments, limitations such as the number of equipment sets, or the multitude of experimental items and large devices, often necessitate group work. With this setup, teachers are often unable to pay attention to individual students' experiment processes, and differences among students are easily obscured by group situations.

In VSETPs, computer software can be used to refine assessment indicators (students studying), cover all key studying process, and achieve accurate process evaluation. It can also collect teaching data, provide timely feedback, and continuously improve the experimental teaching process. It is important to ensure the accuracy of assessment and evaluation in VSETPs by striving for "cost equivalence" and avoiding scenarios where students blindly attempt to achieve results without genuine learning. For example, in real chemistry experiments, an incorrect operation can lead to an explosion, causing personal injury. Similarly, in virtual simulation chemistry experiments, such erroneous operations result in a fictional explosion, and the experiment can judged as 0 points. Moreover, both in real and virtual chemical experiments, a certain erroneous operation can lead to low product yield, which needs to be rated accordingly.

7. Conclusion

Strengthening the practical education teaching process and improving the quality of experimental teaching are of great significance for cultivating innovative talents. In practical teaching, the role of information technology extends beyond a technology upgrade: it represents an elevation of ideas and concepts. Scientific teaching design is the core of change and

sublimation. Director Wu Yan of the Higher Education Department of the Ministry of Education of China pointed out that virtual simulation experiments have facilitated the deep integration of information technology and higher education experimental teaching,. This makes it possible to carry out experimental projects that are otherwise impossible, difficult, or superficial in real environments. These experiments address the global challenges of experimental teaching and mitigate the issue of Chinese university students' lack of hands-on abilities. It is of great significance for improving the quality and fairness (reducing the impact of backward educational equipment in underdeveloped areas) of Chinese higher education.

Abbreviations

NVSETP	The National Virtual Simulation Experimental Teaching Project
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VSETPs	Virtual Simulation Experimental Teaching Projects
VSETP	Virtual Simulation Experimental Teaching Project
MoE	Ministry of Education
VSE	Virtual Simulation Experiment
VSEs	Virtual Simulation Experiments
OBE	Outcome Based Education

Author Contributions

Zhang Liqiu: Writing – original draft, Writing – review & editing

Wang Qining: Conceptualization, Data curation

Liu Lichun: Formal Analysis

Ai Ning: Conceptualization, Data curation, Supervision

Conflicts of Interest

The authors declare no conflicts of interest.

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