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New Teaching Models in the Course of Organic Chemistry Experiment under the Background of "Integration of Science and Education"

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Abstract: *Cultivating talents with strong innovative spirit and capabilities is the primary goal of integrating science and education. Against this backdrop, we have reformed the traditional teaching methods of Organic Chemistry Experimental (OCE) course by adopting the following new instructional models and approaches, achieving excellent teaching outcomes. i) The online OCE course was established on the Zhi Hui Shu teaching platform, as well as abundant teaching materials were created online, such as the learning guide book, the experimental operation video and the exercise library, et al. Furthermore, a blended teaching model combining online and offline instruction were adopted in the teaching of this course. This model ensures students gain more clear understanding of experimental principles, procedures, key points, and challenges before performing experiments, which means that, with the help of the online course, the students engage in pre-class preparation and post-class review more easily, resultantly, they conduct the experimental training in offline laboratories more smoothly. ii) Compared with the way of traditional course evaluation, it has added more assessment points in the teaching of the OCE course. The evaluation of pre-class preparation shifted from submitting pre-class reports to completing the pre-class assignments; for experimental operation scores, the assessments are not only based on overall performance in class (e.g., whether experiments are completed successfully or major operational errors occur), but also on submitted images, videos, or other materials documenting key experimental steps or processes. These added assessment points make the course evaluations more objective, fostering students' sense of responsibility and motivation. iii) research-oriented teaching methods were implemented in this course of OCE to cultivate the students' interest and literacy in scientific research. In this reform strategy, some scientific questions were proposed in traditional verification experiments, thus transforming the verification experiments into the research projects. With the research-oriented method, the students explored some scientific questions collaboratively with their peers, while practicing basic operations. This teaching approach significantly stimulates the students' learning interest and nurtures their research thinking. Otherwise, in this teaching method, students are required to submit research papers in addition to experimental reports, which enhances their academic writing skills. All the above teaching reform models avoid the problem of rigid adherence to instructions, improve the experimental effectiveness, and enhance the student engagement in OCE course.*

Keywords: *Organic chemistry experimental*, *Integrating science and education*, *Online course*, *research-oriented teaching methods*

1. Introduction

Currently, the new round of technological revolution and industrial transformation is accelerating, and the development of new-quality productivity requires high-level integration of multiple innovative production factors, which puts higher demands on the cultivation of innovative talents. As an important technological force in national strategy, universities not only need to output scientific and technological achievements, but more importantly, they need to output talents for the country and society, especially high-level talents with strong innovation capabilities. With the rapid development of China's social economy, higher requirements have been put forward for the cultivation of high-tech talents with innovative spirit. The Integration of Science and Education (ISE) is an effective model for cultivating innovative talents, which is currently the core educational philosophy of many world-class universities.[1-2] Its main goal is to enhance the innovation ability of talents and strengthen the cultivation of top-notch innovative talents. Generally speaking, the ISE starts with cultivating the basic scientific research

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abilities of undergraduate students. During the undergraduate stage, it directly cultivates students' practical abilities, cross-border abilities, innovation abilities, and other "general abilities" to improve teaching effectiveness and learning quality, thereby meeting the demand for high-level innovative talents in the rapidly developing society. [3-4]

In order to achieve the goal of cultivating students' innovation ability through the way of ISE, it is an inevitable historical choice for universities to shift from simple imparting knowledge to equal emphasis on science and education. This means that some traditional teaching models and methods need to be reformed.

2. Problems and Solutions in Traditional OCE course Teaching

At present, there is a common problem in higher education that emphasizes knowledge transmission rather than cultivating students' ability to solve practical problems. Students' innovative spirit and consciousness are not strong. [5] Therefore, reforming teaching models and methods for different disciplines and courses to achieve the educational goal of cultivating innovative talents is of great significance.

Organic Chemistry (OC) is an important branch of the discipline of chemistry. This course is a science that studies the sources, preparation, structure, properties, applications, and related theories and methods of organic compounds. It is an important foundational course for various majors such as chemistry, chemical pharmaceuticals, materials, light industry, textile and food, and pharmacy. Organic chemistry is also an important foundation for the knowledge required by the above-mentioned industries, and it bears the responsibility of cultivating professional talents for industries such as chemical engineering, pharmaceuticals, new materials, and food industry.

The Organic Chemistry Experimental (OCE) course related to OC is a branch of the discipline of chemical experiments and an important practical course. Its main teaching objective is to cultivate students' mastery of basic experimental operations, including basic experimental techniques, various organic reactions and control of reaction conditions, separation and purification of organic compounds, identification techniques, etc. Thus, OCE course is a practical course guided by organic chemistry theory, requiring students to combine theoretical knowledge and solve practical problems through experimental operations during the experimental process. In teaching the OCE course, students are the independent operators, so this course is of great significance for cultivating students' practical and innovative abilities. Traditional teaching procedures mostly start with the teacher's explanation, and the students follow the prescribed procedures to complete experimental operations. This teaching method generally has the following problems: [6-7]

(1) The similarity in the preview report is severe, and the preview has become a formality, and the preview effect cannot meet the classroom requirements. The OCE course has strong practicality, and the content explained by the teacher in the laboratory is relatively limited. The main task of the laboratory time is to conduct experimental operation training, so this course requires a high level of pre-class preparation effect. Under the traditional teaching mode, students' enthusiasm for previewing is not high, and previewing reports are severely similar, making it difficult for teachers to effectively evaluate the quality of previewing. In this teaching reform, information technology will be introduced into teaching. Through online assessments of pre-class preparation, the effectiveness of students' pre-class preparation will be tested, and students will be urged to do pre-class preparation seriously. This can effectively solve the problem of poor quality of pre-class preparation for students.

(2) At present, the teaching of OCE course overly emphasizes the training of chemical experimental operation skills in isolation, which separates the training of basic operation skills from specific experimental exploration. Due to the monotonous and boring training content of isolated experimental operations, the students' interest in learning this course has been weakened. Obviously, the traditional experimental teaching model is not conducive to the cultivation of students' scientific research quality and innovation ability. In this teaching reform, the flipped classroom teaching method is adopted, in which the students conduct explanatory experiments based on sufficient preview, and then teachers provide comments and supplements. This is conducive to enhancing students' interest in learning and improving their learning outcomes.

(3) The traditional experimental teaching procedure is mostly explained by the teacher first, and students follow the prescription to grab the medicine and complete the predetermined steps. This is not conducive to stimulating students' curiosity and interest in exploration, which can easily lead to students'

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fixed thinking patterns and inhibit their innovative thinking. In this teaching reform, scientific questions are drawn from some experimental projects, and reasonable research cases are designed. Students practice basic operations while exploring scientific problems, thereby stimulating their interest in learning.

(4) The evaluation of grades in traditional experimental courses is difficult to be objective. Generally speaking, the grades of laboratory courses mainly consist of three parts: laboratory preview, laboratory operation, and laboratory report. Due to the difficulty for teachers to be familiar with and master every step of the experimental operation process for each student, it is difficult for teachers to objectively and comprehensively evaluate the effectiveness of students' experimental operations. To address this issue, we have added assessment points for students during the experimental operation process.

The reform strategies and measures for the teaching of OCE courses is described in detail below.

3. Reform Practice of Teaching the OCE Course By Combining Online and Offline Methods

3.1 Establishment of the OCE Online Course and Production of the Online Teaching Materials

The widespread application of information technology in the field of education enables dull theoretical knowledge to be presented in multimedia, animation, audio, video and other forms, making the content more vivid and effective in stimulating students' interest in learning. [8] In China, the Zhi Hui Shu website provides a great platform for the establishment and operation of a large number of MOOC courses. [9] We have established MOOC courses on the Zhi Hui Shu teaching platform and developed the following online teaching resources for organic chemistry experiments:

(1) Production of the powerpoint (PPT) presentations of OCE course. For each experiment in this course, we have created PPT presentations in the form of videos, animations, and other materials. All presentations are systematic, vivid, and highlight key points, significantly enhancing students' interest in learning.

(2) Recording of instructional videos. We have recorded complete teaching videos for each experiment offered in the OCE course, including: experimental objectives, experimental principles, experimental steps and phenomena, data processing, etc. Up to now, 22 teaching videos have been recorded as teaching resources for pre-class preview, which make pre-class preview vivid and more easily, thus significantly improve the preview effect.

(3) making the online question library. We have compiled a problem bank containing around 200 practice questions based on the key and difficult points of each experimental project. The main forms of the questions include multiple-choice questions, right or wrong questions, and Q&A questions, expressed through written descriptions or images. The question library is mainly used for pre-class preparation, classroom quizzes, homework, etc.

3.2 Organization and Implementation of the Blended Online-Offline Teaching Model for OCE course

By utilizing the MOOC course of OCE and various teaching resources, we implemented a blended teaching model combining online and offline instruction. Online teaching was conducted on the Zhi Hui Shu online platform, while offline teaching took place in the organic chemistry laboratory. This teaching model is illustrated in Figure 1.

3.2.1 Pre-class Preparation (Online)

Teachers post the teaching videos, multimedia PPT presentations, and preview assignments in the learning resource section of OCE online course three days in advance. Students preview relevant content based on textbooks and the aforementioned online resources, and complete the preview assignments. Only those with passing preview scores are eligible to enter the lab for offline courses. Students who fail the preview can continue studying and practice repeatedly until they pass. By shifting the preview process online and transforming dull content into videos, the difficulty of preview is reduced, and students' interest in preview is enhanced. Setting a passing threshold for preview scores serves as a prerequisite for lab-based operational training, significantly boosting students' sense of responsibility and motivation in preview, thereby effectively ensuring preview outcomes.

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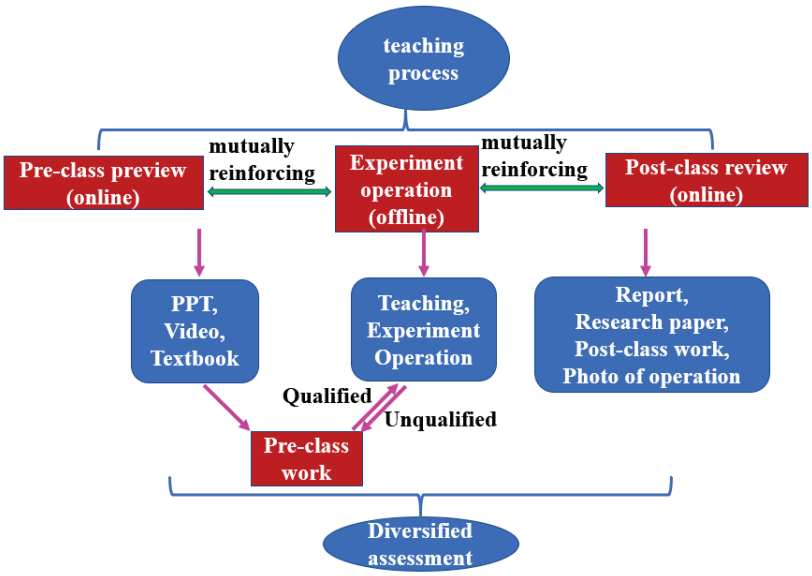

Figure 1: The Blended Teaching Model (Online and Offline Combined).

3.2.2 Experimental Operation (Offline)

The experimental operation is conducted offline in the laboratory. The teacher will explain and demonstrate the content of this experimental operation, and answer the questions encountered by students during their preview. Then the students began to conduct experimental operations. Detailed recording of experimental steps and data is required during the experimental process. After completing the experiment, the teacher will check and sign it before leaving. During the experiment, in addition to completing the operation, it is also necessary to keep good records of the experiment and take photos of important nodes, experimental results, products or data for future reference.

3.2.3. Homework (Online)

After the experiment, students need to finish the experiment report and complete the homework, then submit these materials to the online OCE course. In addition, students are required to submit photos of important milestones in the experimental process (such as experimental setup diagrams, product photos, etc.), videos of important processes (such as changes in the thermometer during boiling point testing, changes in reaction phenomena during the experimental process, measurement of product weight or volume, etc.), and so on. These pictures and videos well record the important nodes of students' operation process and serve as an important basis for evaluating their experimental performance.

3.2.4 Course Evaluation (Online)

Table 1: The proportion of each stage in the score evaluation

Score evaluation system	Proportion
Pre- and post-class assignment	20%
Experiment report	30%
Experiment operation I (overall performance)	30%
Experiment operation II (Data, pictures, videos, etc. during the experimental process)	20%
Total score	100%

The assessment score for each experimental project in this course consists of homework scores (pre-study and post class assignments), experimental operation scores, and experimental report scores. In addition to evaluating the overall performance of experimental operations in class (such as whether the experiment was successfully completed, whether there were major operational errors, etc.), the performance of experimental operations should also be evaluated based on the pictures, videos, and other important experimental nodes or processes submitted by students. Therefore, all aspects of the entire experimental process have received relatively objective and fair evaluations, and the students' grades can basically reflect their true level in the learning process. This evaluation reform ensures the objective assessment of various aspects such as experimental preparation, operation, and homework, enhances the students' attention to the OCE course, and stimulates their serious learning attitude. The proportion of each stage in the score evaluation is shown in Table 1.

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4. Exploration and Implementation of the Research-oriented Teaching Method

In order to strengthen the cultivation of students' innovation ability and scientific thinking, we have explored the Research-oriented Teaching Method (TOTM) for some experimental projects. The process of research-based teaching method is shown in Figure 2.

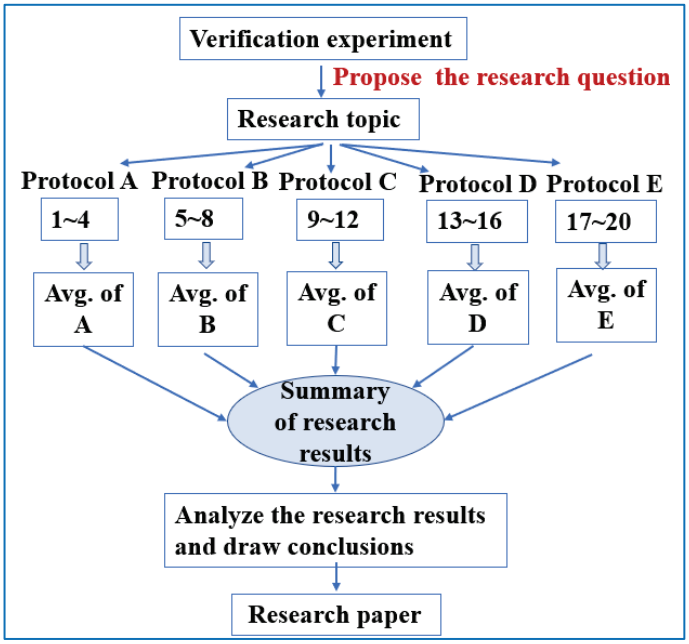

Figure 2: Implementation process of research-based teaching method in organic chemistry course (numbers represent student IDs).

4.1 Transform some confirmatory experiments into research topics

We selected several confirmatory experimental projects from which the research questions were proposed. By changing the experimental steps or research parameters, a series of experimental protocols that could be undertaken by student groups were designed, making each experimental project a research sub topic.

4.2 Implementation of TOTM teaching method

In the experimental course, the students are grouped, and each group is assigned a research protocol. Finally, the research results of each group are summarized together in the form of graphs or tables. By comprehensively analyzing and discussing the experimental results, research conclusions are obtained to solve the problems studied in this experimental project.

As shown in Figure 2, the numbers such as 1, 2, 3, 4, etc. represent the numbering of different groups. The letters A, B, C, etc. represent different research protocols. It can be seen that groups 1-4 execute protocol A, while groups 5-8 execute protocol B, and so on. It can also be seen that groups 1, 2, 3, and 4 independently executed the same protocol, and the average of the experimental results of these four groups is the research result of protocol A. The execution of other experimental protocols was also independently completed by multiple groups. The advantage of this design is that it can avoid significant errors that may occur during the experimental process by different researchers.

4.3 Require the students to submit a research paper after completing each experiment, so as to cultivate their ability to write scientific papers

After the experiment is completed, students need to search for information, process data, analyze and discuss the experimental results. Finally complete the experimental paper. The requirements for the paper include: title, abstract in both Chinese and English, introduction, experimental section, results and discussion, conclusion, references, etc. By writing the simple research papers, we aim to cultivate students' scientific research thinking patterns and their ability to analyze and solve problems.

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4.4 Implementation case of TOTM teaching method - taking the synthesis of ethyl acetate as the example

The synthesis experiment of ethyl acetate (EA) itself is a confirmatory experiment. By the traditional teaching methods, all students are required to complete the synthesis of EA according to the same established steps given in the textbook. According to the TOTM method, we have transformed this experimental project into a simple research topic.

As well-known, in the synthesis of organic compounds, determining the optimal process conditions to achieve the highest yield is always the important research topic. As for the synthesis of compound EA, the ratio of reaction materials, the reaction temperature, the catalyst dosage, and the reaction time are important factors affecting the yield of the product. In response to the question of "how to optimize reaction conditions to achieve the highest reaction conversion rate?", we used the orthogonal experimental method with four-factor and three-level to optimize the above influencing factors. The four factors include raw material ratio (A), reaction temperature (B), catalyst dosage (C), and reaction time (D). For each factor, three parameters were taken (see Table 2). According to the four- factor and three-level orthogonal table, a total of 9 experimental protocols were obtained (see Table 3).

Table 2: The factor and level table (Four-Factor and Three-Level)

Influence factor	Molar ratio of ethanol to acetic acid（A)	reaction temperature (B)	catalyst dosage (C)	reaction time (D)
Level 1	A1	B1	C1	D1
Level 2	A2	B2	C2	D2
Level 3	A3	B3	C3	D3

The whole class were divided into 36 groups, and each experimental protocol were independently completed by four groups of students. The experimental results of the four groups, who had executed the same experimental protocol, were summarized and averaged to give the result of this experimental protocol.

After all the research protocols were completed, the results were evaluated using the orthogonal experimental analysis method, in order to obtain the optimal parameters of each factor with the highest yield, thus obtaining the optimal process conditions for synthesizing the compound EA. This research-oriented experiment has cultivated students' research ideas and methods for optimizing synthesis process conditions.

Table 3: The orthogonal experimental with four-factor and three-level

	A	B	C	D	Yield, K(%)
Protocol I	A1	B1	C1	D1	K1
Protocol II	A1	B2	C2	D2	K2
Protocol III	A1	B3	C3	D3	K3
Protocol IV	A2	B1	C2	D3	K4
Protocol V	A2	B2	C3	D1	K5
Protocol VI	A2	B3	C1	D2	K6
Protocol VII	A3	B1	C3	D2	K7
Protocol VIII	A3	B2	C1	D3	K8
Protocol VIIII	A3	B3	C2	D1	K9
K1	K(A1)	K(B1)	K(C1)	K(D1)	——
K2	K(A2)	K(B2)	K(C2)	K(D2)	——
K3	K(A3)	K(B3)	K(C3)	K(D3)	——
Range					——

In Table 3, among Ai, Bi, Ci, and Di (i=1,2 and 3 respectively) represent different levels of various factors; Ki represents the average reaction yield corresponding to each level in a certain factor, such as:

$$K(A1)=(K1+K2+K3)/3 \quad (1)$$

$$K(B1)=(K1+K4+K7)/3 \quad (2)$$

……

In the above description, the parameter level corresponding to the maximum Ki in each factor is the optimal level. Therefore, the optimal values of four factors A, B, C, and D can be obtained, which is the optimal process conditions for synthesizing the compound EA.

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The range in Table 3 is the difference between the maximum and minimum values of Ki for a certain factor. The larger the range, the greater the impact of this factor on the yield. On the contrary, the smaller the range, the less impact this factor has on the experimental results.

Overall, by the ROTM method, the confirmatory experimental project is transformed into research topic. For each student, the experimental operation in the research project is similar to that in the confirmatory experiment, but the experimental parameters used are different. Therefore, the transformed research topic still undertakes the function of training students in basic experimental operations. And the experimental results of the whole class were combined to complete the research topic and obtain the research conclusion. By designing the research protocol, analyzing the experimental data, discussing the research results, and writing research papers, the students' scientific-oriented thinking and research methods have been cultivated, laying a solid foundation for subsequent comprehensive experiments, open-ended experiments, and high-quality completion of graduation theses.

5. The implementation effect of the new teaching methods

These new teaching models motioned above have been implemented since 2021 in the majors of Chemistry, Chemical Engineering and Technology, Pharmaceutical Preparations, etc. at Qilu University of Technology. The number of experimental projects using ROTM methods has gradually increased to six. In the implementation of the new teaching model, we have summarized our experience, improved the experimental protocol, and gradually improved the teaching effectiveness. The reform ideas of ROTM can be extended to other experimental courses, such as inorganic chemistry experiments, analytical chemistry experiments, physical chemistry experiments, and so on. It can be seen that these new teaching methods have great value for promotion and application. They have shown good teaching effectiveness mainly in the following aspects.

Firstly, the combination of online and offline teaching methods has greatly improved students' enthusiasm for active learning. We have created experimental operation videos and multimedia PPT presentations through information technology, which has increased the fun of learning, reduced the difficulty of learning knowledge, and increased the students' enthusiasm for learning. In addition, we include the results of pre-class assignments and the viewing of online teaching materials in the pre-class grade, which increases the students' emphasis on the pre-class preparation and makes it no longer just a formality. This ensures that students have a clear understanding of the experimental content before entering the laboratory, and have a clear idea of the experiment to be conducted, rather than blindly following the instructions.

Secondly, by using the ROTM methods, some of the confirmatory experiments will be adapted into research projects. In this research topic, each student independently undertakes a research protocol, which includes the complete steps and content of the validation experiment, that is, each student has completed the teaching objectives of the validation experiment. In addition, the experimental results summarized by each group are important evidence for the research topic, and through analysis and argumentation, the conclusions for the research topic can be obtained. In the process of analyzing and demonstrating research results, the students' ability to apply the theoretical knowledge to solve complex scientific problems has been exercised, and their research thinking and innovative spirit have been cultivated.

These new teaching models have brought remarkable improvements in teaching effectiveness for OCE course. i) The preview effect has significantly improved, and the simple problems have been solved during the preview process. ii) More deep questions were asked by the students, and they began to think and analyze the special phenomena that occur during the experimental process. During the experimental operation, the students gained the deeper understanding of the phenomena and other aspects of the experimental process. For example, in traditional teaching, the students often ask questions such as "How should this step be operated?" during the experimental process, while now the frequently asked questions are more profound, such as "What are the reasons for this phenomenon?". This indicates that the students' innovative consciousness has been stimulated. iii) More students are interested in science research. They are actively participating in the research of the teachers' research projects. The enthusiasm of students to participate in the college innovation and entrepreneurship projects, the college experimental skills competitions, and other activities has increased, resulting in the growing in the publication of academic papers and awards.

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6. Conclusion

This project has carried out a series of reforms in teaching methods and modes for the organic chemistry experimental course: (i) using information technology to create a series of online teaching resources and establish a teaching mode that combines online and offline teaching; (ii) Assessment of pre class homework and establishment of assessment criteria for entering the laboratory have effectively ensured the effectiveness of pre class preparation, laying the foundation for students to complete experimental operations with high quality; (iii) The evaluation methods are more diversified, increasing the evaluation points for the experimental process, making the process assessment more objective, and improving students' learning enthusiasm; (iv) Some of the confirmatory experiments were adapted into research-based small topics and taught using research-based teaching methods, which cultivated students' basic scientific research literacy and innovative thinking, and stimulated their interest in learning.

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