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Reforming Organic Chemistry Laboratory Teaching in the Context of Emerging Engineering Disciplines: Strategies and Impacts

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Abstract: In the context of emerging engineering disciplines, experimental teaching plays a crucial role in developing students' engineering practice abilities, especially in application-oriented undergraduate institutions. In chemistry education, the organic chemistry laboratory course is a fundamental core course for chemistry-related majors and holds significant value for students to gain a deeper understanding of chemical knowledge and enhance their practical skills. However, with the continuous evolution of the times, traditional organic chemistry laboratory teaching methods no longer meet the needs of university students or the demands of societal development. This paper uses the organic chemistry laboratory course at the School of Chemical Engineering, Northwest Minzu University, as a case study. It explores various measures such as improving teaching content and methods, incorporating online teaching tools, integrating ideological and political education, reforming the experimental assessment process, and constructing a new learning evaluation system. These reforms aim to develop students' abilities and enhance the quality of teaching. The implementation of these strategies can effectively improve the quality of organic chemistry laboratory teaching, thus contributing to the cultivation of high-level, application-oriented talents.

1. Introduction

Emerging engineering disciplines, known as "New Engineering", represent the direction for the development of engineering education under the requirements of moral education in the new era. It is a necessary response to the demands of the new industrial revolution and an essential strategy to enhance China's national strength and international competitiveness. Practice is the source of innovation, and in application-oriented undergraduate institutions, experimental teaching is a crucial component in cultivating students' engineering practice skills [1]. Therefore, in the construction of New Engineering, the quality of experimental courses is vital to improving the overall quality of talent cultivation. Organic chemistry laboratory courses are mandatory for students majoring in chemistry, chemical engineering, materials science, medicine, and pharmacy. These courses play a critical role in reinforcing students' theoretical knowledge of organic chemistry, developing their experimental skills, enhancing their problem-solving abilities, and fostering innovation. However, traditional organic chemistry laboratory teaching faces challenges such as unreasonable course content design, insufficient teaching equipment, outdated teaching methods, and a lack of student engagement. The traditional experimental teaching model can no longer meet the demands of the current situation, making it imperative for higher education institutions to reform their experimental teaching approaches.

2. Current Status of Organic Chemistry Laboratory Teaching

Taking the organic chemistry laboratory courses at the author's college as an example, traditional organic chemistry lab teaching primarily involves several steps: pre-class preparation, teacher instruction, student experimentation, teacher correction, and post-class submission of lab reports. However, each of these steps has significant shortcomings:

2.1. Pre-Class Preparation

Pre-class preparation tends to be superficial. The common approach is for students to study the experiment on their own and write a pre-lab report. However, most students merely copy the content from the textbook to complete the assigned task, without engaging in deep thinking about the experiment. This approach fails to achieve the intended learning outcomes.

2.2. Classroom Instruction

Students passively receive information with poor outcomes. Organic chemistry experiments often involve numerous reaction equations and mechanisms. Given the limited class time, teachers can only cover key points and demonstrate essential steps, leaving students to passively absorb the information. This limits the time for students to reflect on the material, and the effectiveness of learning varies greatly among students, leading to a lack of deep understanding of key concepts.

2.3. Experimental Operation

Mechanical execution fails to achieve desired results. In organic chemistry experiments, most students simply follow the steps outlined in the textbook. Their observations are not thorough, and they do not engage in thoughtful analysis when encountering problems [2]. This lack of curiosity and exploration stifles imagination and creativity, hindering the development of research skills and causing students to lose interest in organic chemistry experiments.

2.4. Teacher Correction

Teachers cannot attend to all students. With large class sizes, a single teacher may have to guide 20 to 30 students, making it impossible to closely monitor each student's actions. As a result, improper techniques may go unnoticed and uncorrected in a timely manner.

2.5. Post-Class Submission of Lab Reports

Since students often follow the textbook instructions without deeper engagement, many fail to identify, analyze, and solve problems during the experiment. This results in a shallow analysis of experimental data and a lack of reflection. Some students even alter data to align with theoretical expectations, leading to poor-quality lab reports and minimal learning outcomes by the end of the course.

Therefore, how to efficiently complete the teaching tasks of organic chemistry laboratory courses, effectively stimulate students' enthusiasm and initiative for learning, better cultivate their experimental skills and scientific research qualities, and improve the quality of laboratory teaching, has become one of the critical issues facing current reforms in organic chemistry lab instruction. Drawing on years of teaching experience, this article aims to propose a comprehensive curriculum design, focus on teaching strategies, assessment and feedback, to foster an environment where students are motivated to explore and engage deeply with the subject matter. This aligns with the Outcome-Based Education (OBE) teaching philosophy.

3. Strategies for Reforming Organic Chemistry Laboratory Teaching

3.1. Adjusting Course Content and Schedule

In traditional teaching models, there is often a disconnect between organic chemistry theory courses and laboratory courses. Students tend to overlook the close relationship between the two, making it difficult for them to apply theoretical knowledge to solve problems encountered during experiments. As the practical component of the organic chemistry curriculum, the laboratory course should be closely aligned with the theory course. Without changing the total course hours, instructors should adjust the content and schedule of the laboratory course based on the actual progress of the theory course. This alignment ensures that the content and pace of the laboratory work are consistent with the theoretical lessons, thereby strengthening the connection between theory and practice. Such adjustments train students to apply their knowledge flexibly and develop their ability to use theoretical concepts to solve problems. This approach facilitates the application of theoretical knowledge in experiments and helps prevent the disconnect between experimental content and theoretical understanding.

3.2. Reforming the Experimental Classroom

Organic chemistry laboratory work is highly practical, and only through continuous experimentation can students improve their operational skills. Students need to master the basic principles of organic chemistry experiments and deepen their understanding of the fundamental theories through hands-on practice. To enhance the effectiveness of organic chemistry laboratory courses, we have restructured the classroom teaching approach, creating a multi-level organic chemistry experimental teaching system with distinct professional characteristics [3]. This approach aims to stimulate students' interest in learning, foster a rigorous scientific attitude, and lay a solid foundation for future research and professional endeavors. The content of the organic chemistry laboratory is divided into three modules, from which students must choose at least two, depending on their professional requirements.

1) **Basic Knowledge Module of Organic Chemistry Experiments**: This module includes safety rules for the organic chemistry laboratory, safety knowledge, handling of laboratory accidents, an introduction to commonly used instruments, and the writing of laboratory reports. This portion is taught through MOOCs and online resources, making abstract rules, instrument usage, and accident handling more intuitive and dynamic.

2) **Organic Compound Preparation and Basic Operations Module**: This module covers crystallization, melting point determination, distillation, steam distillation, vacuum distillation, optical rotation measurement, synthesis of tert-butyl chloride, synthesis of 1-bromobutane,

synthesis and purification of acetylsalicylic acid, synthesis of ethyl acetate, synthesis of methyl orange, extraction of limonene from orange peel, and extraction of caffeine from tea leaves. Basic operation experiments form the foundation of organic chemistry laboratory courses. Through training in basic operations, students not only standardize their technical skills and enhance their practical abilities but also lay a solid foundation for more complex and innovative experiments. Throughout the experimental process, from simple instrument cleaning, reagent handling, and weighing to assembling complete experimental setups, students receive rigorous, standardized guidance, ensuring they develop solid fundamental operational skills through repeated practice.

3) **Design and Innovation Module**: Design experiments focus on developing students' ability to independently design experiments using their foundational knowledge. Innovation experiments emphasize the integration of various theoretical concepts and aim to cultivate students' ability to apply their knowledge and experimental methods in practical research. Initially, students gain fundamental knowledge and skills through classical organic synthesis experiments. As their abilities improve, design experiments are introduced, in line with the organic chemistry laboratory syllabus and professional characteristics. Students work in groups to consult relevant literature, independently design reasonable experimental schemes, select reagents and instruments, and conduct independent operations. During this process, instructors closely observe and identify any issues, engaging with students in a way that encourages independent thinking and problem-solving. After completing the experiments, students write detailed reports, discussing the principles, methods, procedures, issues encountered, and new discoveries made during the experiments, analyzing data, and drawing conclusions. Design and innovation experiments significantly boost student engagement, allowing them to transition from passive knowledge reception to active inquiry and exploration. This process further develops their skills in expression, problem-solving, hands-on practice, teamwork, and innovation, laying a solid foundation for future research and professional work.

3.3. Integrating Ideological and Political Education into Organic Chemistry Laboratory Courses

Organic chemistry experiments form the foundation of the discipline and are an integral part of scientific research. During the experimentation process, it is crucial to guide students in mastering fundamental research approaches and methodologies, while cultivating their experimental literacy, scientific spirit, and innovative mindset. The highly practical nature of organic chemistry experiments allows the classroom to serve as the primary platform for teaching, while simultaneously leveraging the experimental practice to subtly influence students through ideological and political education. Instructors should focus on integrating these elements into the laboratory curriculum, ensuring that while completing the fundamental teaching tasks, students are encouraged to apply their experimental skills and knowledge in competitive settings such as skills contests and innovation and entrepreneurship competitions, thereby validating the effectiveness of their education in real-world scientific activities.

1) **Cultivating Students' Experimental Literacy and Scientific Spirit**: Beyond imparting organic chemistry operational skills, it is essential to incorporate elements such as truth-seeking, academic integrity, the scientific outlook on development, green development concepts, and environmental protection throughout the experimental process. The goal is to instill in students a dedication to truth, rigorous scholarship, and independent thinking. Educators should emphasize the importance of good experimental practices, including adherence to operational protocols, awareness of safety, environmental consciousness, and the ability to design experiments thoughtfully. For instance, when teaching students to conduct organic chemistry experiments, they should be

instructed to handle materials carefully. While teaching the synthesis of acetylsalicylic acid, instructors should explain that acetic anhydride is a controlled substances, necessitating strict adherence to safe handling and disposal practices. Similarly, when discussing the properties of acetone and diethyl ether, students should be made aware that these solvents can also be used to produce illegal substances, and thus they must be handled with care, in accordance with laboratory standards for controlled substances. Through this approach, students gain both knowledge and an understanding of laboratory safety protocols.

2) **Cultivating Students' Sense of Social Responsibility**: Organic chemistry experiments require attention not only to personal safety and environmental protection but also to societal safety and environmental impact. In designing experiments, students should understand that byproducts generated during reactions are key factors affecting the goals of "green chemistry". During the experiment, instructors must explain how certain processes, such as quenching, extraction, and column chromatography, can contribute to pollution and waste, thereby guiding students to comprehend environmental protection and safety issues. This education fosters a sense of social responsibility and environmental awareness among students, encouraging them to consider and design greener experimental procedures and post-treatment methods. Students should also be made aware of the consequences of misusing chemistry, as history has shown that unethical individuals can turn chemistry into a tool for harm. For example, the case of Liu Zhaohua, who transitioned from a chemistry prodigy to a drug trafficker, serves as a stark reminder of the dangers of moral lapses. Educators must stress the seriousness and implications of such choices, urging students to approach chemistry with a solemn attitude and to learn from these cautionary tales. Moreover, as the misuse of chemicals increasingly threatens ecological balance and human health, students must be instilled with the values of a green economy. Examples of improper agricultural chemical use, mismanagement of industrial waste, overuse of food additives, excessive components in food packaging materials, and antibiotic abuse can serve as cautionary tales. Teachers have a responsibility to nurture students who are conscious of environmental protection and ecological sustainability.

3) **Cultivating Students' Innovative Spirit**: Students are divided into several groups and assigned to research labs under the guidance of graduate supervisors and their mentors. Immersed in the rich research atmosphere of the lab, students' interest in experimentation is greatly stimulated. Throughout the experiment, students take the lead role, while teachers provide guidance and timely support in an inspirational manner. From the design to the implementation of the experiment, students remain in an enthusiastic and exploratory state, engaging in independent thinking and operations as well as mutual exchange and cooperation. Each issue, from its proposal to resolution, sparks students' curiosity and leads to the deepening of their knowledge. This process not only fosters teamwork but also instills a spirit of truth-seeking and the courage to explore [4]. Students are encouraged to drive the development of chemistry through innovative thinking and practice. Strengthening the "Double First-Class" initiative requires the implementation of an innovation-driven development strategy, making this approach essential to achieving "Double First-Class" goals. Innovative thinking requires teachers to instill in students the ability to adapt, tackle challenges head-on, and pioneer new ideas. Research is fundamentally about innovation, and students must understand that organic chemistry is a constantly evolving discipline, where only innovation leads to new discoveries and achievements. Organic chemistry experiments are particularly effective in cultivating students' innovative and practical abilities. The design of experimental plans is a process where students, based on a solid understanding of experimental principles, utilize textbook knowledge to creatively design their own experiments. Therefore, when teaching lab courses, it is crucial to let students actively participate, experience the experimental process firsthand, and identify and solve problems on their own. When issues arise during the

experiment or there are shortcomings in the experimental design, teachers should guide students to apply innovative thinking, encouraging them to independently think, analyze, and attempt to improve the experimental plan. This is a process that inspires and nurtures students' innovative mindset.

3.4. Improving and Refining the Assessment Method

Course assessment is an essential component of organic chemistry laboratory teaching, serving as the primary means to evaluate students' learning outcomes and the quality of teaching. The purpose of organic chemistry lab assessments is to test and reinforce basic laboratory skills, to apply learned knowledge and skills, and to independently complete simple experimental designs and related operations, thereby enhancing the ability to analyze and solve problems comprehensively [5]. Given the current issues in course assessments, instructors should shift from the traditional emphasis on reports over hands-on work to a more balanced approach that values process assessment and practical skills. The goal is to evaluate students' comprehensive laboratory abilities in a more holistic and objective manner.

To build a multi-faceted process-oriented assessment system, the current "regular performance and final examination" model can be further refined. Regular performance should be divided into three parts: pre-lab preparation (30%), lab performance (40%), and lab reports (30%). The pre-lab preparation score is based on watching MOOC lectures, online tests, and pre-lab reports, primarily assessing students' self-learning abilities. The lab performance score includes class attendance, the level of lab operations, and classroom discussions, focusing on practical skills and independent problem-solving abilities. The lab report score assesses data processing and analysis, experimental results and discussions, and intellectual expansion, emphasizing students' data analysis capabilities and logical thinking. Furthermore, the assessment focus varies depending on the type of experiment. For basic synthesis experiments, the emphasis is on evaluating fundamental knowledge and basic operational skills. For design-based and innovative experiments, the focus shifts to assessing students' experimental design and comprehensive analytical abilities.

The final examination involves a design-based experiment. Teachers select 10–15 representative compounds based on fundamental organic chemistry theories, and students are required to randomly draw a topic and design a complete synthesis plan within a set time frame. The plan should include necessary reagents and equipment, experimental procedures, reaction conditions, precautions, and methods for characterizing the products. Students then enter the lab to independently set up the experimental apparatus and conduct a demonstrative operation, with teachers conducting a comprehensive evaluation based on their actual performance. Establishing a diversified assessment approach helps to guide students toward a more serious learning attitude and provides a fair evaluation of their comprehensive laboratory skills.

4. Conclusions

In the context of the new engineering education paradigm, society's demand for talent increasingly emphasizes the cultivation of innovation and practical skills. As a critical foundational course, organic chemistry laboratory classes play a significant role in this regard, making teaching reform essential. This paper addresses the issues in traditional organic chemistry laboratory courses, such as outdated content, monotonous teaching methods, and simplistic assessment strategies. By optimizing and adjusting the course content, utilizing diverse teaching models, and improving assessment methods, the quality of teaching has been significantly enhanced, and students' overall competencies have been comprehensively improved [6]. Through systematic training and learning in lab courses, students are better prepared to transition from novices in research to independently undertaking university-level research projects. This training also provides strong support for expanding students' extracurricular learning and successfully engaging in research work, while strengthening their sense of professional identity and mission as future chemists.

Currently, students have achieved remarkable results in various competitions, including subject contests, student innovation and entrepreneurship projects, innovation training programs, and events like "China International College Students' Innovation Competition" and The "Challenge Cup" China University Student Entrepreneurship Planning Competition. These achievements have sparked students' interest in learning, cultivated their self-directed learning abilities, practical skills, engineering innovation thinking, and comprehensive humanistic qualities. This foundation is crucial for developing application-oriented talents who can meet the needs of national development.

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References

[1] Hofstein, A., & Lunetta, V. N. (2004). The Laboratory in Science Education: Foundations for the Twenty-First Century. Science Education, 88(1), 28-54.

[2] Reid, N., & Shah, I. (2007). The Role of Laboratory Work in University Chemistry. Chemistry Education Research and Practice, 8(2), 172-185.

[3] Marisa G. Weaver, Andrey V. Samoshin, Robert B. Lewis, and Morgan J. Gainer. (2016). Developing Students' Critical Thinking, Problem Solving, and Analysis Skills in an Inquiry-Based Synthetic Organic Laboratory Course. Journal of Chemical Education, 93(5), 847-851.

[4] Seery, M. K., Agustian, H. Y., Doidge, E. D., Kucharski, M. M., O'Connor, H. M., & McDonnell, C. (2019). Developing Laboratory Skills by Incorporating Peer-Review and Digital Badging into Laboratory Practical Classes. Journal of Chemical Education, 96(6), 1098-1108.

[5] Christina Goudreau Collison, Dina L. Newman, Julia Qingli Biehler, Micaela Nelson, Paige O'Brien Daly, Matthew Jackson, Cameron Isaac, Madeline Tebrugge, Jason Anderson, Brian Edelbach, Douglas Tusch, Jeremy Alan Cody. (2022). Reformed Experimental Activities (REActivities): Gauging the Fidelity of Implementation in a Reformed Undergraduate Organic Chemistry Laboratory. Journal of Chemical Education, 99(5), 2032-2043.

[6] Fun Man Fung, Simon Francis Watts. (2019). Bridges to the Future: Toward Future Ready Graduates in Chemistry Laboratories. Journal of Chemical Education, 96(8), 1620-1629.