Exploration of Cultivating Scientific Research Thinking in Organic Chemistry Experiment Course

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Abstract: As an integral component of chemical practical courses, Organic Chemistry Experiment course plays a significant role in cultivating undergraduate application-oriented innovative talents majoring in the fields of chemistry and material. Nevertheless, there are still some problems present in the current Organic Chemistry Experiment course, such as limitations in teaching methods, rigidity in students' thinking patterns, and simplistic evaluation methods. These problems have already restricted the effectiveness of talent cultivation. Taking current problems within the Organic Chemistry Experiment curriculum as starting points, this paper explores pathways to develop students' scientific research thinking. Some course reform measures are proposed from three key aspects: Teaching methods, course content, and evaluation systems. The reform measures in this paper have achieved positive results. These initiatives not only enhance students' ability to apply theoretical knowledge to solving problems in practice, but also effectively foster a rigorous scientific attitude and cultivate scientific research thinking.

Keywords: Scientific Research Thinking; Organic Chemistry Experiment; Curriculum Reform

1. Introduction

Scientific research thinking is the application of scientific knowledge and methodologies to reason through problems, grounded in a respect for facts. An essential avenue for validating and refining this form of thinking is through practice, which often generates new questions and encourages the exploration of novel methods [1]. Therefore, scientific research thinking is embedded in the ongoing process of identifying and resolving issues [2]. Given the backdrop of the "New Engineering" initiative, the cultivation of students' scientific research thinking becomes imperative. As a foundational course pertinent to disciplines such as chemistry, biology, materials science, and environmental science, Organic Chemistry Experiment course is designed not only to develop students' basic experimental skills but also to enhance their ability to merge theoretical knowledge with practical applications. Furthermore, this course requires students to adopt a rigorous scientific attitude in their analysis and problem-solving endeavors [3]. Organic Chemistry Experiment course can play a pivotal role in nurturing students' scientific research thinking. Nevertheless, traditional Organic Chemistry Experimental instruction often suffers from monotonous teaching methods, low student engagement, a lack of autonomous learning and independent thinking, and overly simplistic evaluation mechanisms. These issues hinder the cultivation of students' scientific research thinking and the enhancement of their comprehensive capabilities. This paper analyzes some of the challenges present in the current Organic Chemistry Experiment curriculum, drawing from teaching experiences, and explores potential reforms aimed at better fostering undergraduates' scientific research thinking and improving their practical abilities.

2. Issues Present in the Organic Chemistry Experiment Course

2.1 Limitations in Teaching Methods

As a practical course, Organic Chemistry Experiment course typically requires the completion of instructor-led explanations and student operations within four class sessions. Consequently, the prevalent teaching method involves the teacher providing a concise overview of the experimental principles, procedural steps, apparatus, and precautions, followed by students mimicking the entire experimental process based on the teacher's instructions and the experimental textbook. The course concludes once the experimental procedures are completed [4]. Additionally, the classroom dynamics often reflect a “one-to-many” teaching model [5], which lacks the capacity for tailored guidance for each student. From the instructor’s perspective, this methodology hinders the ability to discern whether students have grasped the relevant experimental principles and content, thereby preventing timely identification of students’ weaknesses during the experimentation process. From the students’ standpoint, the constraints of this teaching approach afford them little opportunity to engage in profound contemplation regarding the experimental principles and methodologies, resulting in minimal learning outcomes.

2.2 Rigidity in Students’ Thinking Patterns

The content of the Organic Chemistry Experiment course primarily consists of verification experiments that detail the experimental steps, reagent quantities, and results, as described in the textbook. These exercises are typically straightforward, exhibit high success rates, and lead students to follow the described procedures to attain results. This engenders a phenomenon of rigid thinking: students become accustomed to conducting experiments strictly according to the textbook instructions or the steps provided by the instructor. When faced with phenomena or circumstances that diverge from expected outcomes, students are often confounded and are unable to independently analyze the reasons behind the discrepancies. Consequently, students do not cultivate an active mindset for independent thought during laboratory courses; their comprehension of experiments remains superficial, and they fail to connect professional theoretical knowledge with practical applications. This lack of curiosity regarding new knowledge and methods precludes them from employing scientific approaches to question and resolve issues. Moreover, the rigidity in their thinking diminishes the importance assigned to pre-experimental preparations, often leading students to mindlessly transcribe textbook content to fulfill preparatory checks, reflecting a lack of initiative in self-directed learning and enthusiasm for experimentation [6]. As a result, subsequent experimental efficiency may be adversely affected. In some cases, students may complete the experimental reports by merely copying textbook information prior to class, submitting them with only data filled in post-experiment, which indicates a neglect for reflection and analysis following their respective experiments.

2.3 Simplistic Evaluation Methods

The evaluation of the Organic Chemistry Experiment course primarily comprises students’ attendance and their scores on experimental reports [7]. Typically, the evaluation of experimental reports emphasizes adherence to formatting standards, neat handwriting, and accuracy of data, while failing to capture students’ thought processes, analytical abilities, and problem-solving competencies during the experiment. Such an evaluation framework risks leading students to mistakenly believe that success in the Organic Chemistry Experiment course is easily attainable, contingent merely upon regular attendance and submission of the reports. This can even result in incidents of data or report plagiarism among peers. Furthermore, the absence of process-based feedback on students’ learning processes limits their understanding of strengths and weaknesses encountered during experiments, making targeted improvements challenging. This simplistic evaluation approach fails to motivate students’ engagement in learning and hinders their mastery of scientific knowledge and methods. Additionally, as a consequence of the lack of authentic feedback regarding student learning trajectories, instructors struggle to adapt and refine their teaching methodologies in a timely manner.

3. Curriculum Reform Measures Aimed at Cultivating Students’ Scientific Research Thinking

Grasping scientific knowledge and methodologies serves as the foundation for cultivating scientific research thinking, which can subsequently be tested and refined through practical application. Therefore, in the context of Organic Chemistry Experiment course, the pathway to nurturing students’ scientific research thinking should focus on their mastery of scientific knowledge and methods, the cultivation of scientific attitudes, and the development of practical skills. Based on this premise, the following reform measures are proposed.

3.1 Adjustment of Teaching Methods

3.1.1 Leveraging online resources for instruction

In light of the rapid advancements in information technology, the Internet offers an abundant array of educational resources. It is essential to select high-quality video materials related to relevant experimental projects available online, such as videos from National First-Class Courses, enabling students to engage in preparatory study and self-directed learning prior to class. Using videos for pre-class study can significantly enhance student' interest. For instance, in instructional videos concerning distillation, fractionation, and extraction, students can visually grasp the correct usage of glassware and adhere to standardized operational procedures. In videos pertaining to organic synthesis experiments, they can familiarize themselves with the intricacies of each experimental step and note critical precautions, including which procedures and operations may impact yield and product purity, the potential toxicity of the reagents employed, proper usage protocols, and appropriate disposal methods for waste liquids. Before the classroom instruction begins, the teacher should pose several pivotal questions concerning the experiment to assess the effectiveness of students' preparatory study; students' responses can be counted as bonus points in their overall evaluation. This approach not only monitors student preparation but also fosters a degree of enthusiasm for learning. In subsequent lectures, Based on students' responses during Q&A sessions, instructors tailor their explanations by providing more detailed or succinct information.

3.1.2 Group practical work

During the experimental processes, students should be in groups of two or three, emphasizing the importance of collaboration and the diligent recording of original data. They must supervise each other to prevent unauthorized alterations to data. Furthermore, we require students to conduct a realistic analysis and summary of any issues or errors encountered during the experiment, noting these observations in their experimental records. Group-based practical work serves not only to cultivate students' skills in teamwork and collaboration but also enables them to learn from each other, mutually inspire one another, and engage in collective exploration and analysis of optimal problem-solving strategies, thereby enhancing the efficiency of the experiment.

3.1.3 Timely teacher summaries

Following the completion of the experiments, the instructor should summarize observations based on the issues noted in students' experimental records. This summary aims to guide students in reflecting upon and analyzing the underlying causes of any problems encountered, organizing and presenting these issues and their causes in the final experimental report. In subsequent projects, the instructor should place greater emphasis on these identified problems. For instance, in the cyclohexene synthesis experiment, the distilled and purified product should ideally be a colorless, transparent liquid; however, some groups may end up with an unexpectedly cloudy liquid. Students should be prompted to consider the reasons behind this outcome. One principal cause is that cyclohexene is insoluble in water, and insufficiently dry glassware during the distillation process mixed residual moisture with the product, leading to cloudiness. Consequently, it is crucial to emphasize to students the importance of maintaining the cleanliness and dryness of apparatus in future experiments, as well as the need to approach every step of the experiment with a rigorous scientific attitude to achieve reliable results.

3.2 Expansion of Curriculum Content

3.2.1 Enhancement of literature research

After the synthesis experiment, students should select typical organic reaction types related to the experimental project and be tasked with conducting thorough research using resources such as the university library, electronic journals, and databases. They should investigate research examples pertaining to the selected reaction types, comparing the synthesis conditions, post-treatment, and yields with the corresponding ones reported in the literature and analyzing the reasons behind any discrepancies. This approach not only broadens students' knowledge horizons and trains their ability to source and critically evaluate useful information [8] but also encourages independent problem analysis, thus fostering their scientific research thinking.

3.2.2 Introduction of experimental design

Following students' learning of fundamental Organic Chemistry Experimental procedures, apparatus, and the synthesis and purification of representative organic compounds, one or two design-based experiments should be organized according to the course arrangements of different disciplines. These experimental projects should encompass the synthesis and purification of organic compounds. The instructor will assign experimental projects that require design, prompting students to create project proposals based on their prior learning and independently researched materials. For example, in the experiment involving the synthesis of ethyl benzoate from benzoic acid and ethanol, students need to design the experimental apparatus and purification methods for the crude product in accordance with the principles of the reaction, contemplating and analyzing critical considerations for the experiment. They should submit their experimental designs in the format of a research report. The process of experimental design necessitates that students flexibly apply their acquired knowledge to address practical problems, thereby honing their ability to integrate theory with practice and enhancing their comprehensive capabilities.

3.3 Reform of the Evaluation System

3.3.1 Enrichment of evaluation content

The evaluation system for this course is designed to encompass a multifaceted approach, enriching the content of the evaluation to provide a more comprehensive evaluation of students' experimental performance. The overall grade for each student in the experimental course consists of their regular performance, final evaluation results, and laboratory report scores. The final evaluation includes an evaluation of experimental operations, experimental apparatus setup, and the content of the experiment itself. Specifically, students will randomly draw an experimental project from those previously studied and select appropriate glassware without adding reaction reagents, and then assemble the apparatus within a stipulated time. The instructor will then pose 2-3 questions regarding the experimental project and the students' operational processes, scoring their performance accordingly. This final assessment not only serves to evaluate students' proficiency in essential laboratory apparatuses and their grasp of significant experimental projects but also helps to cultivate their ability to respond effectively in real-time situations. As for the evaluation of laboratory reports, the focus will shift away from mere adherence to formatting, legibility, and accurate and well-presented data; greater emphasis will be placed on the analysis of experimental phenomena and data, as well as the contemplation of experimental challenges. The aim is to encourage students to engage in a realistic and analytical consideration of their experimental results, thereby nurturing their scientific research thinking.

3.3.2 Enhancement of process evaluation

To achieve a more holistic and objective appraisal of students' performance, the evaluation of the experimental process has been strengthened, with an emphasis on refining the criteria and requirements for regular evaluations. After the completion of each experimental project, instructors will guide students in self-reflecting on the issues encountered and their underlying causes. Students will then evaluate and score their performance in that particular experiment, with the average of all experimental scores serving as their self-evaluation grade. This self-evaluation fosters a deeper understanding of individual strengths and weaknesses during experiments, enhancing self-awareness. Concurrently, instructors will diligently record each student's performance based on classroom observations, considering factors such as initiative and enthusiasm in conducting experimental procedures, the accuracy and thoroughness of data and observations, the precision and adherence to protocols, and the ability to respond effectively to challenges. We compile these evaluations into a final score, augmented by classroom participation points reflecting students' engagement during discussions. This approach encourages students to think critically about issues and participate actively in classroom dialogue. Empirical evidence suggests that the refinement and strengthening of process evaluation significantly contributes to the development of students' rigorous experimental attitudes and habits of self-reflection.

4. Conclusions

This paper addresses several existing challenges within the Organic Chemistry Experiment course, proposing reforms from three critical perspectives: teaching methods, course content, and the evaluation system. Adjustments in teaching methodologies can invigorate students' enthusiasm for active learning, fostering a rigorous scientific attitude and enhancing collaborative skills. The expansion of course content not only enhances students' abilities to apply theoretical knowledge to practical scenarios for effective problem-solving but also elevates their overall competencies. Moreover, reforms in the evaluation system promote the cultivation of rigorous laboratory practices among students. The aforementioned measures within the Organic Chemistry Experiment course serve to effectively facilitate the development of students' scientific research thinking, enhancing their comprehensive capabilities in analyzing and solving problems through scientific knowledge and methodology. Ultimately, these initiatives contribute to the nurturing of innovative, application-oriented talent in undergraduate programs across disciplines such as chemistry, biology, materials science, and environmental studies.

Acknowledgments

This work was financially supported by the Educational and Teaching Reform Project of Hanshan Normal University for the year 2024 (Y.H.S.J. [2024] No. 96-2-30, E24067, E24118).

References

[1] Pan Jiuwu. Discussion on Scientific Research Thinking and Its Types and Characteristics. Shanghai Research on Education, 2009, 02: 78-79.

[2] Zheng Guangfan, Zhao Huaqiu, Sun Jiaqiong. Exploration on Teaching Reform of Organic Chemistry Experiment Course Based on the Integration of Teaching and Research. Biological Chemical Engineering, 2025, 11(1): 174-176.

[3] Jiang Hongli, Dong Jian, Lin Xiaohui, Shen Shili, Zhu Yan. Teaching Reform and Exploration of Organic Chemistry Experimental for Improvement of Scientific Literacy and Innovation Ability. Yunnan Chemical Industry, 2024, 51(4): 193-195+203.

[4] Li Shengying, Lian Qiang, Lai Hongfang, Zhao Chengqiang, Yu Qianqian, Feng Jianhai. Exploration of Teaching Reform for the "Physical Chemistry Laboratory" Course under the Background of New Engineering. Western China Quality Education, 2025, 11(16): 174-177.

[5] Yang Haitao, Liu Shujun, Yan Changge, Liang Hongbo. Organic Experimental Teaching Reform of Training New Chemical Talents under the Background of "Emerging Engineering Education". Chemical Engineering Management, 2024, (33): 48-51.

[6] He Feng, De Ji. Reform and Practice of Organic Chemistry Laboratory Teaching in Higher Education Institutions. China Petroleum and Chemical Standards and Quality, 2024, 44(20): 99-102.

[7] Tang Yucai, Ma Feng, Wang Feifei, Liu Xuewen. Exploration and Practice of Cultivating College Students' Innovation Ability in Local Application-oriented Universities—Taking Organic Chemistry Experiment Courses as an Example. Chemical Engineering Design Communications, 2024, 50(10): 82-84.

[8] Zhong Minghua, Yan Zankai, Cai Longfei, Huang Junsheng. Innovation and Practice of Comprehensive Chemical Experiment Course. Experimental Science and Technology, 2016, 14(4): 121-124.

