Teaching Exploration and Practice of Advanced Chemical Separation Course for Master's Degree Students in Chemical Engineering

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Abstract. Advanced Chemical Separation is a core course for chemical engineering master's students, characterized by its broad scope, interdisciplinary nature, and strong practical orientation. To address challenges such as numerous knowledge points, integration difficulties, rapid updates in frontier knowledge, and insufficient engineering problem integration, the teaching team explored innovative approaches based on the "Three Parallel Education" concept. This includes course content design, teaching mode innovation, and the integration of ideological and political education, providing a reference for the reform of engineering graduate courses in the new era.

1 Introduction

Graduate education is a crucial component of higher education, responsible for nurturing innovative talents for the nation and society, ensuring the realization of an innovative country. Currently, China's economic development is facing challenges of transformation, upgrading, and high-quality development, and people's demand for graduate education is becoming more diversified; The international competition among major powers is becoming increasingly fierce, and the strategic and important role of graduate education is becoming more prominent. Therefore, facing the current problems in graduate education, comprehensively improving the quality of independent talent cultivation, and focusing on cultivating top-notch innovative talents have become important contents of graduate education in China. In the process of graduate education, it is not only necessary to improve students' practical skills, but also to pay attention to the education of theoretical courses. According to the research progress of the discipline, timely adjusting and refining course content, solidifying basic theoretical studies, and emphasizing frontier leadership and methodology are essential to ensure training quality [1-3]. Advanced Chemical Separation, an engineering course on the separation and purification of substances in process industries, is a core course for chemical engineering master's students. It covers principles and applications of mass transfer and separation processes, main unit operations in chemical separation, and recent advances in separation engineering. Utilizing knowledge from undergraduate studies in phase equilibrium, thermodynamics, kinetics, and heat, mass, and momentum transfer, the course addresses separation and purification technologies for complex multicomponent systems in chemical production. For the study of this course, on the one hand, we should start from the commonalities of separation processes, discuss the principles and characteristics of various separation technologies, cultivate professional thinking for graduate students to connect theory with practice, flexibly analyze and solve relevant problems in practical chemical production and design, and adapt to the requirements of modern chemical development; On the other hand, interdisciplinary professional knowledge with certain depth and breadth should be taught and cutting-edge issues should be discussed and exchanged, combined with the future development direction of chemical separation engineering, to optimize course content, enhance innovative thinking, and learn to use engineering thinking to solve relevant practical problems [4-7]. So, fundamentally speaking, advanced chemical separation should be a continuation and supplement of chemical separation, further exploring the basic principles of multiphase separation and complex separation on the basis of undergraduate studies, exploring new technologies, and solving practical production problems. However, due to various reasons such as the lag of textbook content, many higher education chemical separation courses in universities are basically a replica of undergraduate chemical separation courses. The depth and updating of the content are not sufficient, and the teaching methods are limited, which cannot reach the theoretical height that graduate students should have, let alone further connect theory with practice to solve engineering problems.

For this reason, many universities are constantly reforming and trying to improve the higher chemical

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separation course in various aspects. For example, Udugama I. A. from the University of Waikato attempted to introduce digital tools into the curriculum, strengthen course design, and promote the construction of digital platforms [8]; Ravi M. from the University of Leeds emphasizes the role of student feedback assessment in improving chemical engineering education [9]; Reviere A. from Ghent University explained how to connect theory with practical operation through specific experimental teaching [10]; Vasquez E. S. and others from Dayton University explored active learning techniques for online teaching of chemical engineering by developing high-quality videos [11]. Taking the Advanced Chemical Separation course offered by Xi'an University of Technology as an example, this paper explores the necessity of integrating advanced separation science and engineering education into the chemical engineering master's curriculum. It also introduces the course development and teaching model innovation based on recent teaching experiences, aiming to optimize the knowledge structure of graduate students and enhance their innovative thinking, effectively addressing the issues of excessive knowledge coverage and insufficient depth of knowledge points in this course, providing a reference for cultivating interdisciplinary talents with independent innovation capabilities in the chemical engineering field.

2. Teaching objectives of Advanced Chemical Separation course

Advanced Chemical Separation is a discipline focused on the separation, enrichment, and purification of substances, essential to various chemistry-related fields. Therefore, through this course, chemical engineering master's students should achieve the following objectives:

(1) Master the basic theories of modern separation technology and frontier knowledge, understand the latest developments in separation science at home and abroad, and expand their knowledge in the field.

(2) Grasp the principles of different separation technologies, their similarities and differences, and their main application areas, stimulate students' interest in learning through case analysis, literature reports, and class discussions, form independent innovation consciousness, and cultivate students' chemical thinking and ability to analyze and solve chemical separation problems.

(3) Develop a rigorous and realistic scientific attitude and the ability to solve problems related to separation technology, such as the extraction and separation of effective components from natural products, the removal of interfering substances in analysis and testing, and the separation of mixtures in chemical processes, laying the foundation for training high-quality applied chemistry professionals.

3. Key issues to be addressed in the teaching reform of Advanced Chemical Separation course

3.1 The characteristics of this course

The characteristics of this course are mainly reflected in the following three aspects: firstly, it focuses on tracking the development of relevant new technologies and reflecting them in the teaching content. The teaching team has overseas study experience, strong learning ability, and is easy to connect with international standards; The second is to focus on teaching research and teaching reform. Through the research of teaching reform projects, advanced concepts and teaching methods are applied to this course, and the innovative talent cultivation model of "Three Parallel Education" is proposed, which has been implemented effectively. What is "Three Parallel Education"? It mainly addresses the current industry needs for professional skills, aiming at "enhancing professional skills" as the ultimate goal. The discipline creatively proposes the joint cultivation of talent training and talent needs, the balanced emphasis on talent training process and innovation practice, and the parallel alignment of academic frontiers and technical services, building a multi-faceted education sharing mechanism and cooperation platform with base construction as the link; third, it focuses on cultivating students' practical and innovative abilities. Through multimedia + traditional teaching, combined with practice bases, it expands students' practical platforms, cultivating scientific thinking and problem-solving abilities.

3.2 The innovations of this course

Firstly, it is to align with the forefront of the discipline and innovate the teaching content. After more than 20 years of construction and development, this course has continuously updated its teaching content from the initial lecture notes to the textbook, and then from the textbook to the textbook + lecture notes. It has continuously introduced new methods, technologies, and achievements in the forefront of separation science at home and abroad, enriching the connotation of graduate separation courses.

Next is to update teaching concepts and stimulate innovative awareness. Guided by the cultivation concept of "Three Parallel Education", we have created an innovative teaching method of "phenomenon - problem - theory - method" in a step-by-step manner, strengthening the analysis of engineering and technical phenomena and problems; By analysing the evolution of technology and theory, students can understand originality and think about the future; At the same time, explore interactive teaching modes such as MOOC and flipped classroom, allowing students to create independently and openly, so that while learning, students can extend towards "problem exploration" and "independent innovation", achieving a transformation from one-way teaching to two-way discussion.

Lastly, innovate literature research to enhance problem awareness. Conduct literature research on the latest technology of chemical separation, write scientific and technological reports, and communicate through PPT defence to grasp the cutting-edge level of the

discipline and expand the development space of capabilities.

To achieve the teaching objectives of this course, the key issues to be addressed include:

(1) This course covers a wide range of topics with many knowledge points, integrating knowledge from advanced mathematics, analytical chemistry, chemical principles, physical chemistry, chemical thermodynamics, and transfer processes, requiring resolution of connections between different knowledge points.

(2) The diverse separation objects, different separation purposes, various separation technologies, and significant differences in separation scales make traditional teaching monotonous and dull, leading to low student motivation. How to stimulate graduate students' interest in learning, cultivate innovative awareness and thinking requires reform and exploration in teaching to solve individual and common problems.

(3) With technological advancements, separation technologies are continually updated and developed. Graduate education differs from undergraduate education in that new methods and technologies from frontier fields need to be introduced into the teaching process timely, improving students' professional foreign language reading and summarization abilities, strengthening inheritable innovation learning, and solving the systematization of professional courses and the connection with dissertation research.

4. Course teaching content and organizational implementation

As a course for chemical engineering master's students, the content of Advanced Chemical Separation differs from undergraduate separation foundation courses, incorporating new knowledge and technologies from frontier fields in chemistry and chemical engineering, continually optimizing course content

4.1 Carefully selecting textbooks and optimize teaching content

With the acceleration of industrial modernization and technological progress, new chemical separation technologies continually emerge, recognized by the scientific community and gradually applied on a large scale in the industry. Therefore, the teaching content of the chemical separation technology course needs to be updated in sync with technological developments. However, the rich content and limited class hours make comprehensive coverage difficult. Therefore, selecting teaching content and textbooks is crucial. At present, there is no particularly suitable textbook for advanced chemical separation, we use the textbook "Modern Separation Technology and Methods" edited by Professor Ding Mingyu of Tsinghua University and "Chemical Separation Engineering" edited by Deng Xiu as the main references. Although these textbooks reflect an innovative spirit from the perspective of content and system, emphasizes the cultivation of students' ability to combine theory and practice, expands the application fields of chemical separation technology, and can meet the basic needs of cultivating new century talents, as a teaching teacher for graduate students, it is necessary to choose and supplement relevant content to improve the depth of graduate courses.

The course content is mainly divided into two parts: the first part is basic theory, including lectures 1 to 3, introducing an overview of separation science and separation principles, including thermodynamics and kinetics in separation processes, and briefly introducing intermolecular interactions and solvent polarity; the second part is methods and applications, including lectures 4 to 12.

Starting from the fourth lecture, a comprehensive introduction will be given to various new separation technologies. In addition to the conventional liquid-liquid extraction separation, new separation technologies such as micelle extraction, two-phase extraction, solid-phase microextraction, liquid-phase microextraction, supercritical fluid extraction, and molecular distillation will be emphasized. Then, chromatographic separation technology (with a focus on multidimensional chromatography technology), electrophoretic separation technology, and electrochemical separation technology will be discussed; Finally, we will introduce the most widely used membrane separation technology. Throughout the entire teaching process, it is not enough to just focus on textbook content. At the same time, it is necessary to combine disciplinary development and cutting-edge research results, conduct literature research, analyze typical cases, organize students for classroom communication and discussion, stimulate students' learning interest, and expand their research horizons.

4.2 Deeply explore ideological and political education in courses, enrich the content of teaching

Building a "quality demonstration course" involves not only effective learning of course knowledge points but also guiding students to form scientific values and good professional qualities, helping them establish correct worldviews, outlooks on life, and values, realizing the coordinated development of students' knowledge, abilities, and qualities, achieving the educational goal of moral education. In this course, ideological and political elements related to chemical separation are deeply explored and integrated into classroom teaching content, subtly guiding and influencing students. For example, in the introduction chapter, we introduce China's earliest brewing technology, the history of element discovery, and especially Madame Curie's outstanding contributions to the early development of chemistry, enhancing students' sense of professional identity, cultivating students' scientific spirit and exploration spirit. When teaching extraction and separation, introduce the outstanding contributions of Xu Guangxian, the father of rare earths, in the field of rare earth extraction and separation; While explaining membrane separation technology, we introduce the contributions of Chinese-

American scientist Li Nianzhi's invention of liquid membrane separation to separation science. In explaining natural product separation, we introduce Nobel laureate Tu Youyou and artemisinin; When studying new chemical separation technologies, typical cases of green chemistry, such as microfiltration, ultrafiltration, nanofiltration, electrodialysis, etc., are interspersed to enhance students' understanding of green and economical chemical processes in chemical pharmaceuticals and food processing. In short, by incorporating ideological and political elements, not only does it enrich the teaching content, but it also stimulates students' dedication, national pride, and patriotism, which helps to cultivate their correct outlook on life and values [12-14].

4.3 Keeping pace with the times and continually exploring new teaching modes.

This course adopts traditional teaching + multimedia + Internet teaching. Through years of teaching practice, a complete set of PPT courseware and teaching plans have been constructed. To achieve good teaching effects, students are required to preview before class, take notes during class, and review online after class, summarizing and consolidating knowledge. Case analysis and expert reports are a major feature of this course because 80%-90% of investments in chemical or pharmaceutical plants are in separation equipment or units. By analyzing typical cases and reporting the latest research results, graduate students are trained to independently analyze problems and solve engineering technical problems related to the separation of complex material systems. For example, the effective separation of mixed rare earths has always been a topic of concern for separation scientists. Teachers propose separation requirements and key issues that need to be addressed, and students are asked to search for literature, collect materials, formulate plans, and present them in PowerPoint presentations during class. Teachers supplement and comment, and guide everyone to engage in relevant discussions. This approach not only increases students' participation, but also deepens their understanding of the importance of engineering practice and theoretical guidance in practice; As another example, in the production of anhydrous ethanol, the traditional process is based on the relationship between the azeotropic temperature and pressure of ethanol/water (at 193.3 kPa, the lowest azeotropic composition of homogeneous binary is 89.0% ethanol; at 13.3 kPa, its composition is 99.6% ethanol), using a dual tower and dual pressure separation process, which not only requires high-pressure equipment but also consumes energy. This course introduces new membrane distillation technology for the production of anhydrous ethanol, which is efficient and energy-saving, and strengthens students' concept of green chemistry. Expert presentations are also an important part of this course. 2-3 experts are invited to give academic presentations each semester, and students are required to participate and engage in discussions and exchanges. After class, students are encouraged to find answers to thinking questions through literature review, understand the development trends and frontiers of disciplines through literature review, write small papers, expand their knowledge, and form independent innovative thinking through literature reports. This "foundation + frontier" course teaching mode expands the depth and breadth of graduate students' knowledge structures, providing important references for adapting to the development of new quality productivity in the new era.

The Advanced Chemical Separation course has 20 years of teaching practice. Surrounding the course objectives, it continually innovates teaching concepts, content, and methods, combined with its own research directions, deeply explaining research ideas, methods, and typical research results, enriching the teaching process. Students, through this course, master the basic theories and frontier knowledge of modern separation technology, understand the latest developments in separation technology at home and abroad, expand their knowledge in the field, cultivate a rigorous and realistic scientific attitude, and develop the ability to solve problems related to separation technology. The teaching results are excellent. Evaluations from peers, supervisors, and students indicate that the course content is systematic and advanced, the teaching objectives are clear, the classroom content is rich, the teaching links are scientifically designed, and fully reflect the educational philosophy of "student-centered, innovation ability cultivation first".

5. Conclusion

Graduate education is an advanced education system crucial for cultivating high-level scientific and technological talents in China. The quality and level of graduate education affect not only the scientific research and academic capabilities of universities but also the country's scientific and technological and innovation capabilities. The chemical industry is a major pillar industry of China's national economy, and chemical separation is an important structural unit in chemical processes. It is key to supporting the chemical field's progress toward becoming a chemical power. The teaching quality of the chemical separation course directly affects the training quality of graduate students. Therefore, based on years of teaching practice, this paper analyzes the importance and necessity of teaching this course from the perspective of chemical discipline and industry development. It introduces the experience of constructing the Advanced Chemical Separation course at our university from course design, classroom teaching, and ideological and political education, aiming to further improve the graduate training system that integrates learning and research, leveraging the "Internet+" education model, pay attention to the adoption of new media and new cases, and focus on student participation, integrating high-quality digital education resources, and incorporating frontier results into classroom teaching to ensure teaching quality.

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References

1. Ministry of Education. (2014) Opinions on Improving and Strengthening Graduate Course Construction.http://www.moe.gov.cn/srcsite/A22/s7065/201412/ t20141205182992.html.
2. Deviney, A. V., Classen, J. J., Martin-Ryals, A., Cortus, E.L., Bird, K., Brewer, C.E., Kaleita, A.L., Miller, D.N., Rodriguez, L.F., Stone, M., Vance, C.C. (2024) Perspective: Expanding Transdisciplinary Collaborative Research to Graduate Education. J. ASABE, 67(3): 743-747.
3. Velegol, S. B., Bullard, L. G., Bayles, T. M., Cadwell, K. (2023) National Trends and Models for Teaching-Track Faculty in Chemical Engineering. In: ASEE Annual Conference and Exposition, Conference Proceedings. Maryland. pp.39602
4. Sadikin, A. N., Yusof, K. M., Aziz, A. A., Hassim, M. H., Yamani, Z. Y., Mustaffa, A. A., Hamid, M.K.A. (2017) A Multi-Year Study of Professional Skills Development among First Year Chemical Engineering Students. Chem. Eng. Trans., 56:1453-1458.
5. Stanklewicz, A. I., Henczka, M., Molga, E. S. (2021) Teaching Chemical Engineering in Europe - Developments, Dilemmas and Examples. Chem. Process Eng.-INZ, 42:321-335.
6. Wang, Y. Q., Li, Y. N., Yang, F. S., Zhao, X. L., Han, X. L., Zhao, B. X., Chen, L. Y., Wu, Z., Ma, X. X. (2018) Reform and Innovation of Mutiform Practical Teaching in Chemical Engineering. In: 1st IEEE International Conference on Knowledge Innovation and Invention. Jeju. pp. 355-358.
7. Nie, B. H., Chen, D. C., Fan, T., Chang, M. L. (2018) Exploration of Chemical Separation Engineering Course Teaching for Applied Talent Cultivation. Guangzhou Chem. Ind., 46(13): 159-160.
8. Udugamal, I. A., Atkins, M., Bayer, C., Carson, J. Dikicioglu, D., Gernaey, K. V., Glassey, J., Taylor, M., Young, B. Y. (2023) Digital Tools in Chemical Engineering Education: the needs and the desires. Educ. Chem. Eng. 44: 63-70.
9. Ravi, M. (2023) Evolving trends in student assessment in chemical engineering education. Educ. Chem. Eng. 45: 151-160.
10. Reviere, A., Jacobs, B., Stals, I., De Clercq, J. (2024) Cross-curricular project-based laboratory learning enables hands-on interdisciplinary education for chemical engineering students. Educ. Chem. Eng. 47: 1-19.
11. Vasquez, E. S., Elsass, M. J. (2021) Work in Progress: Active Learning Techniques for Online Teaching of Chemical Engineering Courses. ASEE Annual Conference and Exposition, Conference Proceedings, July 26.
12. Zhang, H. X., Song, L. L., Yin, Y. H., Mou, S. L. (2023) Exploration and Practice of Ideological and Political Teaching in Chemical Separation Engineering Course. Chem. Eng. Higher Edu., 40(5): 35-39.
13. Ge, X. Z., Li, Y., Han, Y. P., Du, F. X., Liu, H. M. (2020) Tu Youyou and Artemisinin from The Perspective of Science and Ideology. Education Teach. Forum, 16: 59-62.
14. Zhang, L., Zhang, Y., Li, S. M., Zhang, B. Q., Zhong, S. Y., Zhang, Z. G., Zhan, J. (2023) Exploration of Ideological and Political Content and Approaches in The Master's Degree Course of 'Advanced Separation Engineering'. Chem. Eng. Times, 37(5): 68-70.