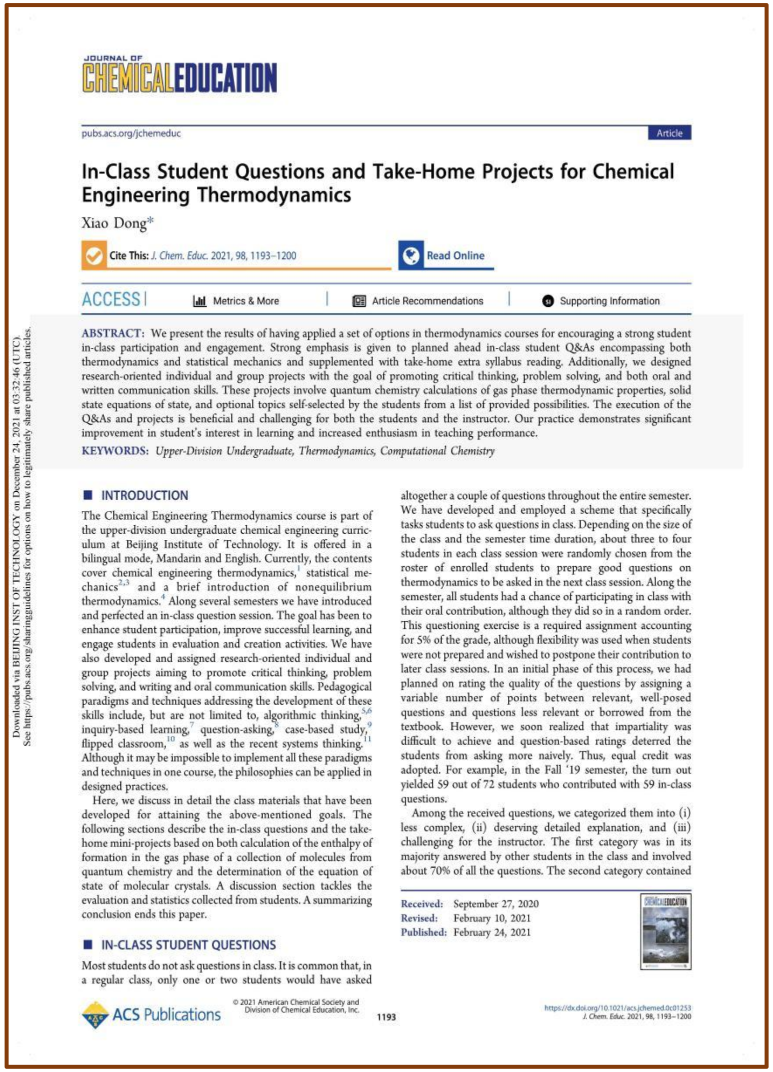
部分论文首页



JOURNAL OF CHEMICAL EDUCATION

pubs.acs.org/jchemeduc Article

In-Class Student Questions and Take-Home Projects for Chemical Engineering Thermodynamics

Xiao Dong*

Cite This: J. Chem. Educ. 2021, 98, 1193−1200 Read Online

ACCESS | Metrics & More | Article Recommendations | Supporting Information

ABSTRACT: We present the results of having applied a set of options in thermodynamics courses for encouraging a strong student in-class participation and engagement. Strong emphasis is given to planned ahead in-class student Q&As encompassing both thermodynamics and statistical mechanics and supplemented with take-home extra syllabus reading. Additionally, we designed research-oriented individual and group projects with the goal of promoting critical thinking, problem solving, and both oral and written communication skills. These projects involve quantum chemistry calculations of gas phase thermodynamic properties, solid state equations of state, and optional topics self-selected by the students from a list of provided possibilities. The execution of the Q&As and projects is beneficial and challenging for both the students and the instructor. Our practice demonstrates significant improvement in student's interest in learning and increased enthusiasm in teaching performance.

KEYWORDS: *Upper-Division Undergraduate, Thermodynamics, Computational Chemistry*

INTRODUCTION

The Chemical Engineering Thermodynamics course is part of the upper-division undergraduate chemical engineering curriculum at Beijing Institute of Technology. It is offered in a bilingual mode, Mandarin and English. Currently, the contents cover chemical engineering thermodynamics,[1] statistical mechanics[2,3] and a brief introduction of nonequilibrium thermodynamics.[4] Along several semesters we have introduced and perfected an in-class question session. The goal has been to enhance student participation, improve successful learning, and engage students in evaluation and creation activities. We have also developed and assigned research-oriented individual and group projects aiming to promote critical thinking, problem solving, and writing and oral communication skills. Pedagogical paradigms and techniques addressing the development of these skills include, but are not limited to, algorithmic thinking,[5,6] inquiry-based learning,[7] question-asking,[8] case-based study,[9] flipped classroom,[10] as well as the recent systems thinking.[11] Although it may be impossible to implement all these paradigms and techniques in one course, the philosophies can be applied in designed practices.

Here, we discuss in detail the class materials that have been developed for attaining the above-mentioned goals. The following sections describe the in-class questions and the take-home mini-projects based on both calculation of the enthalpy of formation in the gas phase of a collection of molecules from quantum chemistry and the determination of the equation of state of molecular crystals. A discussion section tackles the evaluation and statistics collected from students. A summarizing conclusion ends this paper.

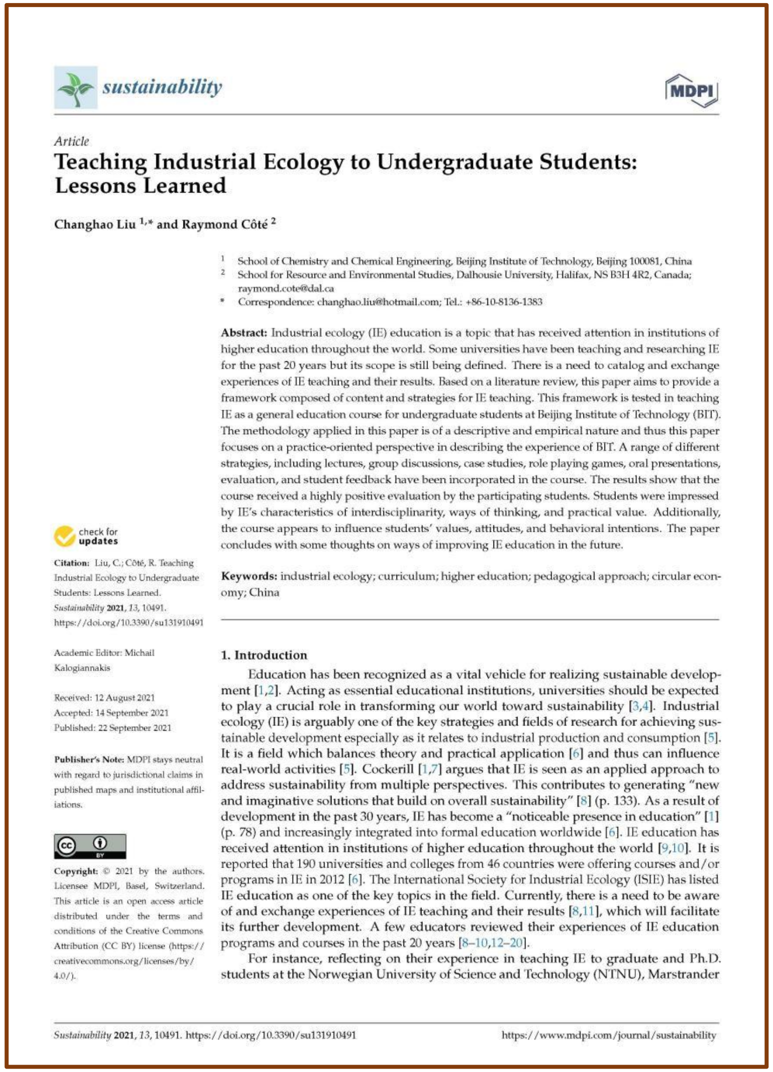
IN-CLASS STUDENT QUESTIONS

Most students do not ask questions in class. It is common that, in a regular class, only one or two students would have asked altogether a couple of questions throughout the entire semester. We have developed and employed a scheme that specifically tasks students to ask questions in class. Depending on the size of the class and the semester time duration, about three to four students in each class session were randomly chosen from the roster of enrolled students to prepare good questions on thermodynamics to be asked in the next class session. Along the semester, all students had a chance of participating in class with their oral contribution, although they did so in a random order. This questioning exercise is a required assignment accounting for 5% of the grade, although flexibility was used when students were not prepared and wished to postpone their contribution to later class sessions. In an initial phase of this process, we had planned on rating the quality of the questions by assigning a variable number of points between relevant, well-posed questions and questions less relevant or borrowed from the textbook. However, we soon realized that impartiality was difficult to achieve and question-based ratings deterred the students from asking more naively. Thus, equal credit was adopted. For example, in the Fall '19 semester, the turn out yielded 59 out of 72 students who contributed with 59 in-class questions.

Among the received questions, we categorized them into (i) less complex, (ii) deserving detailed explanation, and (iii) challenging for the instructor. The first category was in its majority answered by other students in the class and involved about 70% of all the questions. The second category contained

Received: September 27, 2020
Revised: February 10, 2021
Published: February 24, 2021

https://dx.doi.org/10.1021/acs.jchemed.0c01253
J. Chem. Educ. 2021, 98, 1193−1200



sustainability MDPI

Article

Teaching Industrial Ecology to Undergraduate Students: Lessons Learned

Changhao Liu [1,*] and Raymond Côté [2]

1 School of Chemistry and Chemical Engineering, Beijing Institute of Technology, Beijing 100081, China
2 School for Resource and Environmental Studies, Dalhousie University, Halifax, NS B3H 4R2, Canada; raymond.cote@dal.ca
* Correspondence: changhao.liu@hotmail.com; Tel.: +86-10-8136-1383

Abstract: Industrial ecology (IE) education is a topic that has received attention in institutions of higher education throughout the world. Some universities have been teaching and researching IE for the past 20 years but its scope is still being defined. There is a need to catalog and exchange experiences of IE teaching and their results. Based on a literature review, this paper aims to provide a framework composed of content and strategies for IE teaching. This framework is tested in teaching IE as a general education course for undergraduate students at Beijing Institute of Technology (BIT). The methodology applied in this paper is of a descriptive and empirical nature and thus this paper focuses on a practice-oriented perspective in describing the experience of BIT. A range of different strategies, including lectures, group discussions, case studies, role playing games, oral presentations, evaluation, and student feedback have been incorporated in the course. The results show that the course received a highly positive evaluation by the participating students. Students were impressed by IE's characteristics of interdisciplinarity, ways of thinking, and practical value. Additionally, the course appears to influence students' values, attitudes, and behavioral intentions. The paper concludes with some thoughts on ways of improving IE education in the future.

Keywords: industrial ecology; curriculum; higher education; pedagogical approach; circular economy; China

check for updates

Citation: Liu, C.; Côté, R. Teaching Industrial Ecology to Undergraduate Students: Lessons Learned. *Sustainability* **2021**, *13*, 10491. https://doi.org/10.3390/su131910491

Academic Editor: Michail Kalogiannakis

Received: 12 August 2021
Accepted: 14 September 2021
Published: 22 September 2021

1. Introduction

Education has been recognized as a vital vehicle for realizing sustainable development [1,2]. Acting as essential educational institutions, universities should be expected to play a crucial role in transforming our world toward sustainability [3,4]. Industrial ecology (IE) is arguably one of the key strategies and fields of research for achieving sustainable development especially as it relates to industrial production and consumption [5]. It is a field which balances theory and practical application [6] and thus can influence real-world activities [5]. Cockerill [1,7] argues that IE is seen as an applied approach to address sustainability from multiple perspectives. This contributes to generating "new and imaginative solutions that build on overall sustainability" [8] (p. 133). As a result of development in the past 30 years, IE has become a "noticeable presence in education" [1] (p. 78) and increasingly integrated into formal education worldwide [6]. IE education has received attention in institutions of higher education throughout the world [9,10]. It is reported that 190 universities and colleges from 46 countries were offering courses and/or programs in IE in 2012 [6]. The International Society for Industrial Ecology (ISIE) has listed IE education as one of the key topics in the field. Currently, there is a need to be aware of and exchange experiences of IE teaching and their results [8,11], which will facilitate its further development. A few educators reviewed their experiences of IE education programs and courses in the past 20 years [8–10,12–20].

For instance, reflecting on their experience in teaching IE to graduate and Ph.D. students at the Norwegian University of Science and Technology (NTNU), Marstrander

基于 OBE 和 EHS 理念的制药过程安全与环保课程体系建设*

尹宏权**　陈甬雪
(北京理工大学化学与化工学院　北京　102488)

摘要　“制药过程安全与环保”为制药工程专业本科生必修核心课程，但其课程体系不完善，基于 OBE 和 EHS 理念，从课程目标、课程内容、课程思政、教材、教学方法、课程考核与评价方法等方面对该课程进行了建设和完善，取得了一些创新性成果与经验，制定了教学目标，创新性地设置了课程内容，开展了课程思政，主编了教材，提出了适宜的教学方法，建立了课程考核与评价方法，可以为全国其他高等院校类似课程的教学与建设提供有益的借鉴。

关键词　制药过程安全与环保　课程体系建设　制药工程
DOI：10.13884/j.1003-3807hxjy.2021110051

作为制造业大国，我国拥有很多的医药生产企业，其中中小企业居多，许多制药企业发展非常迅速，为我国经济发展和人民生命健康事业做出了巨大贡献。不过，制药企业也暴露了大量安全与环保问题。制药工业具有生产技术复杂、危险因素多的特点，例如，在化学原料药生产过程中，一般用到较多的化学单元反应，如氯化、还原、氢化、卤化等，且往往有副反应发生，有些原料和中间体具有易燃易爆性、腐蚀性等；还包含诸多单元操作，如回流、蒸馏等。因此，工艺操作与参数控制非常复杂，而且在连续化生产过程中多是管道输送，操作技术复杂、多样。这些都说明制药过程的危险性高，发生安全事故的风险高[1]。我国制药企业的环保现状是：产业结构低端，污染严重；污染物对环境影响的研究不足等[2]。另外，我国制药企业的安全与环保意识不足，安全与环保管理水平有待提高，安全与环保管理技术有限等。因此，安全与环保问题成为我国制药企业的突出问题之一，制药企业的安全与环保问题频频被曝光，引起了社会和舆论的强烈关注。

制药是关乎人类大健康的产业，同时制药过程本身也是与环境、健康、安全（EHS）问题联系在一起。而且，制药企业的安全与环保问题既为制药行业敲响警钟，也对高校制药工程专业教育与教学提出了新的要求。鉴于以上背景，应广大制药企业工作者的强烈要求，在《制药工程教学质量国家标准》中，制药过程安全与环保被列为制药工程专业本科生必修的核心课程。但是，由于课程建设时间不长，该门课程的课程体系，包括课程目标、课程内容、课程思政、教材、教学方法、课程考核与评价方法等迫切需要建设和完善。

OBE（outcome-based education）理念是一种先进的教育理念，其遵循的原则是：成果导向、以“学生为中心”和持续改进[1,3-5]。EHS（environment，health，safety）理念，即环境、健康和安全管理理念，体现了人文关怀，强调企业的社会责任、绿色环保、本质安全和可持续发展，具有三大优势，第一是实现系统管理，有效持续改进；第二是实现预防为主，全过程控制；第三是实现体系融合，推进全面管理[6-9]。笔者以 OBE 和 EHS 理念为指导，对该课程开展了系统性的建设和完善，取得了一些创新性成果与经验。

1　制药过程安全与环保课程体系建设

1.1　课程目标

根据 OBE 和 EHS 理念，北京理工大学制药过程安全与环保课程教学团队对照该课程对应的毕业要求，拟定该课程的教学目标是：(1) 熟悉制药过程健康、安全与环保知识，能够在健康、安全、环境等现实约束条件下，评价设计方案的可行性；(2) 能够运用制药工程健康、安全与环保知识分析并合理评价制药工程实践对健康、安全与环保的影响，并能够理解应承担的责任；(3) 理解制药工程领域关于环境保护方面的方针、政策和法规；(4) 掌握制药企业的 EHS 管理知识；(5) 课程思政目

* 北京理工大学“信息技术与教育教学深度融合专项　制药过程安全与环保 MOOC 建设”；北京理工大学教改项目“面向化学、化工类本科专业‘健康、安全与环保（HSE）’模块化课程教学研究”
** 通信联系人，E-mail：hqyin77@bit.edu.cn

分子氢键供体的键参数与振动光谱之间的定量关系

张汝波*　张绍文*
(北京理工大学化学与化工学院　北京　100081)

摘要　通过简单量子化学计算，使学生获得系列羰基化合物/水分子之间几何和振动光谱参数，通过构建氢键供体键长与其伸缩振动波数之间的定量关系，进而理解氢键受体的碱性在氢键供体的共价键长、伸缩振动频率及其氢键强度中的重要作用。基于中学和大学教学内容，引入这种研究式教学方法能够很好地使学生把化学中的相关概念关联在一起，提升学生学习化学的兴趣和解决科学问题的能力。

关键词　氢键强度　供体碱性　共价键长　分子振动光谱　计算化学
DOI：10.13884/j.1003-3807hxjy.2023030193

氢键对超分子结构的稳定性和分子催化性能等有着重要作用。在中学和大学化学课程教学中，一般都会介绍氢键（X　H···Y）的形成、强度以及对物质的物理性质和化学性质的影响[1-2]。以往的研究基于氢键的本质，介绍和探究了典型氢键的强度与供体 X　H 的酸性和受体 Y 的碱性之间的线性关系[3-4]，并已经将其作为本科生结构化学课外教学内容之一。但是，对于环形氢键形式，只能研究氢键供体和受体的酸碱性综合效应，不能指出酸性或碱性对氢键形成的作用。基于化学教学的基本内容，利用简单的计算化学手段，建立“准确测量”的 X　H 键长与其键强度之间的定量关系，发现这一定量关系的可能原因，帮助学生理解和应用教材中提到的共价键强度、分子光谱等一系列概念。研究式教学的目的就是帮助学生把化学中的原理和概念关联在一起，避免知识内容碎片化和单纯地记忆，提升学生学习化学的兴趣，培养逻辑思维，拓展知识维度。

1　原理介绍

与键强度相关的量，在结构化学教学里面主要涉及到了键能、键级和化学键力常数等。对于 X　H···Y 氢键，在受体 Y 的影响下，X　H 共价键键长一般比自由的、未形成氢键时的 X　H 键长要长，X　H 共价键的强度降低，X　H 伸缩振动波数变小。如果 X　H 共价键键长的变化量与其化学键力常数建立某一定量关系，我们就可以通过准确“测量”X　H 键长，得到 X　H 共价键键的强度，进而可以“测量”X　H···Y 的氢键强度。

首先，选择一系列含有羰基官能团的化合物与一个水分子形成的 1∶1 型水簇的结构。利用基本计算化学知识，通过水簇结构很容易获得水分子中 O_w　H 的键长。对于 O_w　H···O（O_w 是水中的氧原子，O 是羰基中的氧原子）氢键体系，O_w　H 键长的变化量 $\Delta R_{O_w\ H}$ 可以定义为：

$$\Delta R_{O_w\ H}=R_{O_w\ H}(\text{水簇})-R_{O_w\ H}(\text{自由水分子}) \quad (1)$$

分子光谱中的化学键力常数通常表示为：

$$k=4\pi^2c^2\nu_e\mu \quad (2)$$

k 是化学键力常数，c 是光速，ν_e 是经典振动波数，μ 是 O_w　H 的折合质量。公式 (2) 清楚地表明，分子中某一基团的化学键力常数与其经典振动波数成正比。

根据量子化学原理，求解微观粒子的薛定谔方程，可以得到其运动状态和能级。对于分子体系，通过求解其中原子核运动的薛定谔方程，能够得到分子中原子之间的振动波函数和能级，并在此基础上得到相应振动的波数和力常数。因此，通过量子化学计算可以预测描述化学键强度的振动波数和力常数。目前国内外通用量子化学计算程序均提供了计算方法，可以计算得到这些物理量。利用简单的量子化学计算方法，优化分子的稳定结构，并在此基础上，用相同计算方法做频率分析，可以获得分子的简谐振动频率，从而得到所研究的自由水分子和其与化合物形成的 1∶1 型水簇中 O_w　H 经典振动波数。利用式 (3) 很容易得到 $\nu_{O_w\ H}$ 的相

* 通信联系人，E-mail：zhangrubo@bit.edu.cn；swzhang@bit.edu.cn

2022 年第 43 卷第 20 期　　化　学　教　育(中英文)(http://www.hxjy.chemsoc.org.cn)　　· 49 ·

实验教学

干燥实验中干燥曲线的处理方式讨论*

李中泽　刘文芳**　王　烨　赵之平
(北京理工大学化学与化工学院　北京　102488)

摘要　在干燥特性曲线的测定实验中，先根据物料含水量（X）随时间（t）的变化，绘制出干燥曲线（X-t），求导得到干燥速率（U），再对 X 作图得到干燥速率曲线（U-X）。由于测得的 X-t 数据点较多，U-X 曲线波动较大，因此选用合适的数据处理方式以得到准确的 U-X 曲线对于研究干燥过程至关重要。比较了 X-t 曲线的几种处理方式，结果表明，当区间较小时，差商法会造成 U-X 曲线较大的波动，增加取差商的区间可降低波动，但区间过大可能导致 U-X 曲线丢失部分重要细节；相比之下，对 X-t 平滑处理后再取微分可明显减小波动，且保持 U-X 曲线趋势不变。另一个比较好的处理方法是分段拟合，得到的 U-X 曲线可明确划分不同阶段以及获得更为准确的关键数据；除了线性拟合外，U-X 曲线的降速阶段也可用双曲线模型拟合，均有较好的拟合效果。

关键词　化工原理　干燥实验　干燥曲线　数据处理
DOI：10.13884/j.1003-3807hxjy.2021060197

化工原理及化工原理实验作为大化工类专业的基础课程，对学生的工程能力培养起着至关重要的作用。化工原理实验可以将理论与实践充分结合，培养学生的操作能力、创新能力、实验数据处理能力、实验结果讨论能力等，为后续的专业实验课程及相关研究打下良好的基础[1]。在化工原理干燥特性曲线的测定实验中，先根据物料含水量随时间的变化绘制出干燥曲线，然后再对干燥曲线进一步处理求得干燥速率，用干燥速率对含水量作图得到干燥速率曲线[2]。由于使用重量传感器测得的数据点密集，导致由此计算的湿物料的干基含水量以及干燥速率波动较大[3]。干燥速率曲线的形状对判断和划分干燥过程的不同阶段以及确定恒速干燥阶段干燥速率和临界含水量至关重要，而它在很大程度上取决于对干燥曲线的处理方式。有的学生对干燥曲线取差商后计算干燥速率，进而绘制干燥速率曲线；还有的学生直接对曲线进行平滑降噪处理；还有的则采用对干燥曲线拟合的方式，然后再求导得到干燥速率曲线；不同的处理方式会对实验结果产生较大的影响。为此，针对干燥曲线的不同处理方式进行了详细的比较和讨论，以期为这一实验的教和学提供有益的帮助。

1　实验简介

1.1　实验目的

本实验的目的是了解洞道式干燥装置的基本结构、工艺流程和操作方法；掌握恒定干燥条件下物料干燥曲线和干燥速率曲线的测定方法；掌握不同干燥条件、物料性质对干燥速率、临界含水量的影响；了解湿物料的临界含水量以及恒速阶段对流传热系数的测定方法。

1.2　实验原理

这里只介绍干燥曲线和干燥速率曲线的测定原理。在恒定干燥条件下，干燥速率与干燥时间的关系如式（1）[4]所示：

$$U = -\frac{G_c \mathrm{d}X}{A\,\mathrm{d}t} \tag{1}$$

式中 U 为干燥速率（单位：$g \cdot m^{-2} \cdot s^{-1}$），$t$ 为干燥时间（单位：s），A 为物料与空气接触的总表面积（单位：m^2），X 为物料含水量（单位：$g \cdot g^{-1}$），G_c 为绝干物料质量（单位：g）。

在干燥实验过程中，记录不同干燥时间 t 下湿物料的质量 G（单位：g），直到物料质量不再变化时为止。物料最终含水量记为平衡含水量 X^*。由于实验条件有限，暂以干燥结束后的物料质量近似作为绝干物料质量 G_c。物料含水量如式（2）所示：

$$X = \frac{G - G_c}{G_c} \tag{2}$$

在恒定干燥条件下，将物料含水量 X 对干燥时间 t 作图，得到 X-t 曲线，称为干燥曲线。将干燥速率 U 对物料含水量 X 作图，得到 U-X 曲线，称为干燥速率曲线。

1.3　干燥条件和实验数据

干燥实验装置采用洞道式干燥器[5]，规格为

* 北京理工大学本科教改项目"化工原理线上线下混合一流课程建设""化工原理实验的虚实结合、线上线下混合式教学探索"
** 通信联系人，E-mail：liuwenfang@bit.edu.cn

ISSN 1002-4956
CN11-2034/T　　实　验　技　术　与　管　理
Experimental Technology and Management　　第 37 卷　第 11 期　2020 年 11 月
Vol.37　No.11　Nov. 2020

DOI: 10.16791/j.cnki.sjg.2020.11.043

能源化工专业实验教学模式的探索与改革

翟　雪，乔金硕，孙　旺，黎汉生
（北京理工大学 化学与化工学院，北京　102488）

摘　要：文章分析了北京理工大学能源化工专业实验教学存在的问题，介绍了该校化工实验中心探索并实践的新型专业实验教学模式，涉及教学资源的建设与完善、课程考核办法和标准的制定，以及教学质量的监控等三个方面，并以"阴极极化曲线的测量"实验为例，介绍了新型教学模式的应用。

关键词：能源化工；专业实验；实验教学模式；探索与改革
中图分类号：G642.0　　**文献标识码**：A　　**文章编号**：1002-4956(2020)11-0205-04

Exploration and reform of experimental teaching model for energy and chemical engineering specialty

ZHAI Xue, QIAO Jinshuo, SUN Wang, LI Hansheng
(School of Chemistry and Chemical Engineering, Beijing Institute of Technology, Beijing 102488, China)

Abstract: This paper analyzes the problems existing in the experimental teaching of energy and chemical engineering specialty in Beijing University of Technology, and introduces the new professional experimental teaching model explored and practiced by the Chemical Engineering Experimental Center of Beijing University of Technology, which involves the construction and improvement of teaching resources, formulation of curriculum assessment methods and standards, and monitoring of teaching quality. By taking the "Measurement of cathode polarization curve" experiment as an example, the paper introduces the application of the new teaching model.

Key words: energy and chemical engineering; specialized experiment; experimental teaching model; exploration and reform

能源化工是现代工业的重要组成部分，包括新能源技术、可再生能源技术及低碳经济能源技术等，其以国家未来国家新能源产业需求为目标，与关系未来人类生存环境和人类生活的一些重要战略性新兴产业密切相关。实验实践教学，特别是专业实验以及专业创新实验等实践性教学环节，是连接理论知识与工程实践的桥梁，是培养工科学生岗位职业能力的重要途径[1-4]，对于学生理论联系实际的工程素质以及解决实际问题能力和创新能力的培养具有重要作用[5-8]。

我校"能源化学工程专业实验"课程，包括面向能源化学工程专业学生的 64 学时（2 学分）能源化工实验 A 课程（必修课），以及面向全校相关专业学生的 32 学时（1 学分）能源化工实验 B 课程（选修课）。在教学过程中，我们运用 OBE 理念，以学生的产出为导向，着重培养学生工程实践能力和独立解决问题能力，将信息技术与实验教学相结合，吸取以往教学模式的经验教训，启用新式教学平台、教学模式与教学方法，有效解决了原有的诸多问题，而且为实践实验类教学课程的未来发展提供了广阔的空间。

1　能源化工专业实验教学存在的问题

1.1　传统教学模式存在诸多问题

传统的实验教学模式是以教师为中心、讲义为中心、课堂为中心的，为教师单向传授、学生被动接受的局面[9-11]。这种模式存在如下问题：①实验预习形式化。学生按照实验讲义进行预习，甚至有不预习、抄袭预习报告的现象，预习效果不佳。②学生独立操作课时少。上课时由于任课教师要重复讲授讲义中的基本理论知识、操作方法和注意事项等内容，使得学生独立操作课时比例较少，没有充足的时间锻炼学生的动手实践能力。③机械式操作。由于上课过程中缺

收稿日期：2020-04-07
作者简介：翟雪（1988—），女，黑龙江五常，硕士，实验师，研究方向为本科实验教学、实验室管理。
E-mail: 6120170016@bit.edu.cn