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Exploration of Teaching Reform in "Instrumental Analysis" under the Background of Industry-Education Integration: A Case Study of Shandong Institute of Petroleum and Chemical Technology

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Abstract: Under the dual impetus of the high-quality development of higher education and industrial transformation and upgrading, the integration of production and education has emerged as the core pathway to address the disconnect between university curriculum teaching and industrial demands, as well as to enhance the quality of talent cultivation. As a foundational course for engineering disciplines including chemistry, chemical engineering, environmental science, and materials science, "Instrumental Analysis" functions as a pivotal carrier that bridges theoretical knowledge with experimental practice, and integrates academic research with industrial applications. Notably, its teaching quality exerts a direct influence on the development of students' practical operational capabilities and career adaptability. Taking the "Instrumental Analysis" course as the research subject, this study is grounded in the concept of talent cultivation through the integration of production and education, and systematically dissects the prominent issues inherent in traditional courses regarding teaching content, teaching methodologies, practical resources, and evaluation systems. Accordingly, reform strategies are proposed from four dimensions: the reconstruction of teaching content, the innovation of teaching models, the upgrading of practical systems, and the optimization of evaluation mechanisms. Furthermore, a novel trinity teaching paradigm encompassing "basic theory – social application – cutting-edge scientific research" is constructed, which provides practical references for nurturing industry-adaptive talents equipped with solid theoretical foundations, strong practical capabilities, and outstanding innovative literacy.

1. Introduction

Instrumental Analysis is an interdisciplinary applied course centred on modern analytical instruments, integrating knowledge from multiple disciplines such as chemistry, physics, electronics, and computer science[1]. The subject under discussion functions as a pivotal conduit between foundational theoretical frameworks and industrial practices. In the context of ongoing industry transformation and upgrading, there has been an increased emphasis on the competencies required from future talent. These include a depth of theoretical knowledge, proficiency in instrument operation, the ability to analyze complex samples, and competence in solving engineering problems.

However, the traditional teaching model of "Instrumental Analysis" is increasingly inadequate in meeting the dual demands of industrial transformation and upgrading and the connotative development of higher education, with its prominent issues manifested in four aspects[2]. Firstly, the teaching content overemphasizes classical theoretical principles but insufficiently covers mainstream modern analytical technologies and practical industrial scenarios, leading to a significant disconnect from actual industrial needs. Secondly, dominated by teacher-centered lectures and experimental demonstrations, the teaching methodology lacks interactive and inquiry-oriented designs, leaving students passively acquiring knowledge and hindering the development of their active thinking and innovative practice abilities. Thirdly, practical teaching is confined to on-campus confirmatory experiments, preventing students from engaging with real industrial problems such as complex sample analysis and instrument malfunction diagnosis. Fourthly, the evaluation system, centered on final theoretical written examinations, focuses on knowledge retention while neglecting the comprehensive assessment of key competencies like practical operational skills and innovative thinking. These structural contradictions result in students' disjointed theory and practice, inadequate career adaptability, and failure to meet the industry's demand for high-quality applied talents.

As a key initiative for deepening educational reform, the integration of production and education is centered on breaking down the barriers between universities and enterprises, achieving in-depth integration of educational and industrial resources, and facilitating the positive interaction of "promoting production through education, supporting education with production, and coordinating production and education"[3]. As an application-oriented undergraduate university specializing in petrochemical engineering, Shandong Institute of Petroleum and Chemical Technology leverages its industrial background and regional industrial advantages to actively explore the pathway of integrating production and education in the teaching of "Instrumental Analysis". By reconstructing teaching content, innovating teaching models, and other effective strategies, the university addresses the dilemmas of traditional teaching, accordingly providing a practical paradigm for enhancing course teaching quality and cultivating industry-adaptive talents.

2. Analysis of Current Situation and Problems in Traditional "Instrumental Analysis" Teaching

2.1 Outdated Teaching Content

2.1.1 Insufficient Coverage of Cutting-edge Technologies

Traditional teaching content tends to focus on the principles and operation of classic analytical technologies, such as UV-Vis spectrophotometry, atomic absorption spectrometry and gas chromatography. However, explanations of modern technologies, such as HPLC-MS, GC-MS, in situ infrared online analysis and laser Raman spectroscopy, tend to be brief and lack systematic teaching on practical applications, such as industrial complex sample pretreatment, trace pollutant detection and product quality control systems. Research shows that hyphenated technologies such as HPLC-MS and GC-MS account for over 65% of applications in the petrochemical industry. However, related content occupies less than 20% of class hours in traditional courses. This indicates a significant discrepancy between technical teaching and industrial practice.

2.1.2 Insufficient Coverage of Cutting-edge Technologies

General textbooks are predominantly used, with cases such as "heavy metal detection in soil" and "COD determination in water" that are poorly integrated with petrochemical production realities. The absence of real enterprise cases hinders students' ability to connect theoretical knowledge with industrial application scenarios, resulting in weak knowledge application capabilities and insufficient professional adaptability.

2.2 Single and Rigid Teaching Methods

2.2.1 Lack of Diversified and Innovative Designs

Many teachers still adopt the traditional "PPT lecture + experimental demonstration" model. Although some courses incorporate video resources, virtual simulation tools and interactive platforms that visualize abstract instrument principles and complex operations are rarely used. Excessive teacher dominance leads to passive knowledge acquisition, lacking opportunities for independent thinking and inquiry-based learning, which suppresses students' enthusiasm and hinders the development of innovative and critical thinking.

2.2.2 Poor Transformation between Theory and Practice

Classroom teaching prioritizes theoretical knowledge, while experimental teaching mainly consists of confirmatory experiments. Students follow preset protocols without opportunities for independent experimental design, condition optimization, data analysis, or result evaluation. This model causes the disconnection between theoretical knowledge and practical skills, limiting students' ability to solve real engineering problems.

2.3 Weak Practical Teaching System

2.3.1 Restricted Practical Operation

Limited availability of instruments and venue constraints hinder practical teaching, resulting in insufficient hands-on opportunities for students. This severely restricts the development of their practical and problem-solving abilities.

2.3.2 Imperfect University-Enterprise Collaborative Education Mechanism

Existing cooperation mostly remains at shallow levels such as "visit-based internships" and "lecture-based exchanges". Enterprises lack enthusiasm for teaching participation, and long-term cooperation mechanisms are absent. Students rarely gain access to enterprise analysis centers or production workshops for real sample testing, missing exposure to practical work such as complex sample processing, instrument maintenance, and data quality control.

2.4 Imperfect Evaluation System

The traditional evaluation system is dominated by final theoretical examinations (accounting for 70%-80% of total scores), with low weight on practical assessment[1]. Evaluation criteria mainly focus on experimental report completion and basic operation standardization, lacking comprehensive assessment of experimental design, innovation, data processing, and problem-solving abilities. This guides students to prioritize knowledge memorization over practical skills and comprehensive literacy, failing to fully reflect their learning outcomes and capabilities.

3. Teaching Reform Strategies for "Instrumental Analysis" under Industry-Education Integration

3.1 Optimize Teaching Content for Precise Alignment with Industrial Demands

3.1.1 Dynamically Update Teaching Content

In order to maintain a competitive advantage in the field of instrumental analysis technology, it is essential to integrate the most recent theoretical concepts and instrumentation[2]. A trinity content system, integrating "classic theory, modern technology and industrial application" is recommended. It is imperative to acknowledge the necessity of incorporating contemporary methodologies, such as HPLC-MS, GC-MS, and in-situ infrared technology, while maintaining a commitment to the utilization of fundamental classic technologies. In order to expand the professional horizons of students and enhance their knowledge renewal capabilities, it is essential to incorporate cutting-edge research achievements.

3.1.2 Integrate Practical Production Scenarios

The text focuses on the characteristics of the petrochemical industry, and real enterprise cases are collected, including "Determination of benzene and toluene in gasoline by GC-MS", "Analysis of phenolic pollutants in chemical wastewater by HPLC-MS", and "Catalytic reaction monitoring via in-situ infrared technology". The integration of these elements into classroom teaching through case analysis and problem inquiry is a pedagogical strategy that has been demonstrated to facilitate students' application of theoretical knowledge to the resolution of engineering problems.

3.2 Innovate Teaching Models to Promote University-Enterprise Collaborative Teaching

3.2.1 Implement "Case-Project" Driven Teaching

The reconstruction of classroom processes around typical research projects and industrial problems is imperative. In the context of theoretical teaching, practitioners are wont to select illustrative cases from research projects or industry practice, thus guiding students to explore via problem chains: The questions can be included: "What is the practical problem that this research is designed to address?" "How should the experimental scheme be designed in order to improve sensitivity and accuracy?" "How should data deviations be troubleshot?". Through group discussions, debates, and presentations, students are encouraged to engage in problem analysis and solution design, transitioning from a passive listening mode to an active inquiry approach. The integration of research data, experimental phenomena, and extant literature is conducive to exposing students to authentic research scenarios, thereby enhancing their analytical and problem-solving abilities.

3.2.2 Enrich Modern Teaching Tools and Resources

The construction of an "industrial virtual simulation laboratory for instrumental analysis" is proposed, incorporating modules such as gas chromatograph fault diagnosis, online chemical wastewater monitoring, and complex sample pre-treatment. The utilization of immersive teaching methodologies serves to complement the constraints imposed by physical laboratory settings. The establishment of an online university-enterprise collaborative platform is imperative, integrating training videos, operation manuals, real test data, and industry standards. This platform should facilitate online question-and-answer sessions, case discussions, and project collaboration. The integration of industrial software, such as Origin, Jade and ChemDraw, into the curriculum is recommended to enhance students' proficiency in data processing and report writing skills.

3.2.3 Conduct "Classroom-in-Enterprise" Teaching

The establishment of collaborative educational frameworks with industry entities is paramount, encompassing the organization of students for immersive pedagogical experiences within analysis centres and production workshops. Guided by the expertise of enterprise technicians, students engage in practical sample testing, acquiring proficiency in instrument operation specifications, maintenance procedures, and quality control standards. This model has been shown to enhance professional identity and practical skills, achieving seamless alignment between classroom teaching and enterprise job requirements.

3.3 Strengthen Practical Teaching to Enhance Students' Practical Capabilities

3.3.1 Construct a "Three-Level Progressive" Practical Teaching Platform

It is necessary to establish a progressive platform consisting of on-campus basic laboratories, university-enterprise joint laboratories, and enterprise practice bases, in accordance with the training logic of "basic operation – comprehensive application – innovative practice". Basic laboratories focus on the training of fundamental skills with conventional instruments; joint laboratories introduce advanced equipment (GC-MS, HPLC-MS) to simulate enterprise environments for comprehensive/design-oriented experiments; enterprise bases provide on-the-job training, graduation design, and innovation opportunities for real-world engineering practice.

3.3.2 Deepen University-Enterprise Cooperation for Resource and Talent Sharing

It is recommended that investment in on-campus practical teaching be increased, with the aim of facilitating the acquisition of industrial-grade instruments such as GC-MS, HPLC-MS and in-situ infrared spectrometers. The establishment of "shared laboratories" in collaboration with enterprises is imperative for the effective allocation of equipment, human resources, and physical spaces. These shared laboratories facilitate the delivery of training programmes for students, educators, and personnel, fostering collaborative research and professional development. It is recommended that a "double tutor system" be implemented, whereby enterprise tutors are complemented by on-campus tutors. In order to enhance practical teaching relevance and effectiveness, it is further advised that technical experts be invited to participate in experimental teaching, project guidance and graduation design evaluation.

3.3.3 Promote Research-Teaching Integration for Innovation Cultivation

The design of innovative and entrepreneurial projects is to be based on teachers' research and enterprise R&D needs, with the objective of encouraging students to participate in project applications and implementation. It is imperative to translate research achievements into teaching cases and experimental projects (e.g., new detection methods) with a view to enhancing content, cutting-edge thinking and innovation.

3.4 Optimize Evaluation System to Construct a Multidimensional Assessment Mechanism

3.4.1 Establish a Multidimensional Comprehensive Evaluation System

It is imperative that a holistic evaluation is implemented, encompassing online learning outcomes, classroom performance, experimental operation, and final examinations. Online evaluation focuses on homework completion and discussion participation; classroom evaluation emphasizes questioning, group collaboration, and initiative; experimental evaluation assesses operation standardization, data processing, and report quality; and final examinations comprehensively evaluate knowledge mastery. This comprehensive approach provides insights for the enhancement of pedagogical practice.

3.4.2 Introduce Multiple Evaluation Subjects

The construction of a multi-subject mechanism involving "teacher evaluation + enterprise evaluation + student peer evaluation" is recommended. Teachers are responsible for the assessment of learning processes and the evaluation of ability improvement. Enterprise tutors, meanwhile, are tasked with the evaluation of professional quality, practical skills and problem-solving abilities during internships. Finally, peer evaluation focuses on contribution and collaboration in group work. The employment of multiple perspectives serves to ensure an objective and comprehensive evaluation of learning outcomes and professional adaptability.

4. Case Study: Teaching Reform Implementation at Shandong Institute of Petroleum and Chemical Technology

As an application-oriented undergraduate university in Shandong Province, Shandong Institute of Petroleum and Chemical Technology has advanced in-depth industry-education integration reform in "Instrumental Analysis" teaching, forming an industry-specific model with the following measures:

4.1 Develop Cutting-Edge, Industry-Aligned Teaching Content

A collaborative approach is recommended for the purpose of revising syllabuses, with enterprise experts being instrumental in this process. The integration of one to two authentic petrochemical analysis challenges within each chapter is recommended, with the objective of stimulating interest. New theories (e.g. clean energy via water electrolysis, near-infrared online analysis, industrial quality control) and enterprise cases should be incorporated. Concluding theoretical classes with the latest research achievements and English literature has been demonstrated to be an effective method to broaden horizons and enhance professional English proficiency of students. The organisation of "academic salons" is recommended, with the purpose of facilitating the dissemination of research findings and the facilitation of in-depth student discussion.

4.2 Innovate Integrated Theory-Practice Teaching Model

It is recommended that a combined model of "case teaching + flipped classroom + project training" be adopted. The programme is designed to guide students towards mastery of analytical principles through case analysis in theoretical teaching, with flipped classrooms facilitating group case solution presentations. The design of experiments that are both comprehensive and design-oriented is essential for enhancing the effectiveness of practical teaching. Examples of such experiments include the analysis of catalyst phases using XRD, the determination of C3-C5 hydrocarbons in gasoline using GC, and the detection of trace phenols in wastewater by spectrophotometry.

4.3 Build Diversified Practical Talent Training Platforms

It is vital to complement classroom teaching with extracurricular activities, such as academic competitions, innovation training and internships. The integration of research and teaching laboratories is conducive to the sharing of resources, thereby enabling students to access state-of-the-art technologies and instruments. The establishment of "open innovation laboratories" is recommended for conducting independent experiments and facilitating research participation. The organisation of internships at multiple bases is recommended in order to familiarise students with the entire analysis process (sample collection, processing, testing, data analysis, report writing). Collaborations with enterprises are to be initiated in order to offer order classes, thereby enhancing employment competitiveness.

4.4 Implement Diversified Evaluation Focused on Comprehensive Quality

Multi-dimensional evaluation, aligned with course objectives, is to be adopted, with emphasis placed on knowledge construction, ability improvement, and value development. It is imperative to employ formative evaluation techniques such as classroom-based instant assessment (Q&A, discussions, group work, quizzes), homework, online learning, and unit tests to assess educational and innovative outcomes.

5. Evaluation and Reflection on Teaching Reform Effects

5.1 Reform Effect Evaluation

The following conclusions can be drawn from the evaluation of the aforementioned cases of teaching reform implementation:

5.1.1 Enhanced Student Learning Interest and Initiative

After the teaching reform, the integration of teaching materials, real projects, and cutting-edge research has resulted in a transformation of students from passive to active learners, thereby significantly improving learning outcomes. The implementation of interactive methods and the adoption of flipped classrooms has been demonstrated to enhance engagement and cultivate interest.

5.1.2 Strengthened Practical and Problem-Solving Abilities

The closed loop between theory and practice established through industry-education integration has enhanced students' operational skills, problem-solving capabilities, innovative thinking, and teamwork. Group tasks and enterprise internships have fostered professional ethics and industry awareness, boosting employment confidence and competitiveness.

5.1.3 Promoted Teacher Professional Development

Project-based teaching has raised requirements for teachers, prompting them to update knowledge and technical reserves, strengthen enterprise cooperation, and adapt to talent training needs. This has advanced the construction of a "double-qualified" teacher team.

5.2 Reform Reflections and Improvement Directions

Despite the success of the teaching reform, there are still some issues and shortcomings. The following are reflections and improvement suggestions for the aforementioned issues:

5.2.1 Deepen University-Enterprise Cooperation

Addressing the issues of shallow cooperation and unstable enterprise participation can be achieved by the signing of long-term strategic agreements, the establishment of mechanisms for joint course development, textbook compilation, teacher team building, and quality evaluation, and the setting up of special funds and regular seminars.

5.2.2 Improve Teachers' "Double-Qualified" Competence

In order to address the deficiencies in enterprise experience and technical update capabilities, it is imperative to establish teacher enterprise practice systems, encourage participation in R&D projects, and organise training by enterprise experts. This approach will facilitate the development of a team that possesses a robust foundation in both theoretical concepts and practical expertise. In order to address the limitation of access to advanced instruments and concentrated off-campus bases, a number of measures were implemented. These included the augmentation of funding, the procurement of additional industrial-grade equipment, the expansion of practice bases, and the establishment of instrument sharing mechanisms.

5.2.3 Optimize Practical Resource Allocation

In order to address the limitation of access to advanced instruments and concentrated off-campus bases, a number of measures were implemented. These included the augmentation of funding, the procurement of additional industrial-grade equipment, the expansion of practice bases, and the establishment of instrument sharing mechanisms.

6. Conclusion

Industry-education integration provides a core pathway and methodological support for "Instrumental Analysis" teaching reform. Taking Shandong Institute of Petroleum and Chemical Technology as an example, this study addresses traditional teaching problems by constructing a trinity teaching paradigm ("basic theory – social application – cutting-edge scientific research") from four dimensions, leveraging petrochemical industry characteristics and university-enterprise cooperation advantages. Reform practice has verified its effectiveness, as evidenced by improved student interest, comprehensive abilities, and teaching quality. As an ongoing process, future reform should further strengthen university-enterprise cooperation, enhance teacher competence, optimize practical resources, and improve evaluation systems to cultivate more applied talents adapting to high-quality industrial development.

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References

[1] Tang, K., Lin T.,Shi Z.X., Qiao J., Xie C.Y., and Du L.X. (2024) Reform of Teaching Practice of Modern Instrumental Analysis in Biotechnology Programs. Agricultural Biotechnology, 13, 93-95.

[2] Meng, F.D., Huang, Q.X., Cai Y.B., Ji W.C., Fan X.J., and Xu, Q. (2024) Research on the Curriculum Reform of Instrument Analysis under the Background of "New Engineering" Talent Training. Curriculum and Teaching Methodology, 6(10).

[3] Lin P. (2025) Synergistic Pathways for Digital Talent Cultivation and Efficiency Enhancement in Enterprise Administration from the Perspective of Industry-Education Integration. New Explorations in Education and Teaching, 3(10).