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International Journal Of Modern Engineering Research (IJMER)

# Curriculum Reform of "Bioreaction Engineering" Based on the Cultivation of Engineering Practice Ability

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***ABSTRACT:*** *Bioreaction Engineering is a core course in bioengineering, featuring strong engineering attributes, complex formulas, and close integration of theory and practice. However, it is widely regarded as "difficult to learn and teach" due to students' weak mathematical foundations, limited engineering thinking, and disconnection between theory and practice.To address these issues, this reform centered on developing students' engineering practice ability through restructuring course content, applying AI-generated knowledge maps, and adopting a hybrid online–offline model for personalized learning. Typical industrial cases were introduced to link theory with real engineering problems, complemented by enterprise visits and co-teaching with industry mentors. A student-centered formative assessment system and integrated engineering course cluster further enhanced learning coherence.The reform effectively improved students' learning motivation, engineering thinking, and ability to solve complex engineering problems, offering a replicable model for cultivating innovative, practice-oriented engineering talents.*

***KEY WARDS:*** *Bioreaction Engineering; Curriculum Reform; Engineering Practice; Case-Based Teaching; Hybrid Learning*

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Date of Submission: 11-12-2025 Date of acceptance: 22-12-2025

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## I. INTRODUCTION

### *1.1 Course Characteristics*

Bioreaction Engineering is a core course in the bioengineering program, distinctly reflecting the nature and characteristics of an engineering discipline. It is an interdisciplinary subject grounded in biology, chemistry, and engineering, focusing on the common engineering and technical issues involved in bioreaction processes. The course is designed for third-year undergraduate students majoring in bioengineering, with prerequisite courses including Advanced Mathematics, Principles of Chemical Engineering, Biochemistry, Physical Chemistry, Microbiology, and Cell Biology.

The course content is organized into several major instructional units, including the fundamentals of biology and engineering, reaction kinetics (covering both enzyme and microbial kinetics), bioreactor operation, and transport processes. Its core objective is to integrate theoretical principles with industrial applications, enabling students to perform engineering analysis and design of bioreaction processes. Ultimately, the course aims to enhance students' ability to apply multidisciplinary knowledge in solving complex engineering problems.

### *1.2 Teaching Challenges*

Since 2017, the instructor has taught this course over multiple academic cycles and has consistently found it to be recognized by both teachers and students as one of the most challenging courses in the bioengineering curriculum—"difficult to learn and difficult to teach."[1]

From a knowledge perspective, the course is formula-intensive and heavily dependent on prerequisite subjects such as Advanced Mathematics and Chemical Engineering Principles. Students, especially those with weak mathematical foundations, often struggle to progress through the material, finding each conceptual step difficult to master. From a competency perspective, the course embodies typical features of engineering education, where the focus lies in solving real-world engineering problems. However, students frequently experience a disconnect between theory and practice and face difficulties in developing systematic engineering thinking. As a result, they often fall short of the program's high-level objective—cultivating the ability to address complex engineering problems effectively.

Within the broader curriculum structure, Bioreaction Engineering occupies a pivotal position in the bioengineering course cluster. It is closely linked with related courses such as Fermentation Engineering and Bioprocess Equipment, serving as a critical foundation for subsequent studies. More importantly, it plays an irreplaceable role in fostering students' engineering mindset and practical problem-solving skills.

Therefore, the objective of this curriculum reform is to address these instructional challenges by helping students establish engineering thinking, strengthen the connection between theory and practice, and develop the capability to solve complex engineering problems—laying a solid foundation for the cultivation of outstanding engineers.

## II. MATERIAL AND METHODS

This project focuses on reforming the *Bioreaction Engineering* course, involving two third-year classes with a total of 60 students. The reform begins with a thorough review of the course objectives, positioning the cultivation of engineering practice skills as the central goal[2]. Course content was restructured into concise, well-defined modules that emphasize key and challenging topics while eliminating redundancies. A set of 6–8 representative case studies forms the instructional backbone, adopting a problem-driven approach[3] to integrate both online and offline learning activities. Furthermore, the assessment system was redesigned to prioritize formative, process-oriented evaluation, rather than relying solely on final examinations[4]. This approach establishes a scalable and transferable teaching model that can be adapted and extended to other courses within the engineering curriculum.

## III. RESULTS AND DISCUSSIONS

### *3.1 Reform Objectives and Key Issues*

The primary goal of this reform is to enable students to develop **engineering thinking** and acquire foundational engineering practice skills, thereby enhancing their ability to tackle complex engineering problems.

From a knowledge perspective, the course is formula-intensive and heavily reliant on mathematical foundations, which poses significant challenges for students. From a competency perspective, as a typical engineering course, it emphasizes the application of knowledge to real-world problems. However, students often struggle to bridge theory and practice and find it difficult to cultivate systematic engineering thinking. As a result, they fall short of the program's high-level objective of effectively solving complex engineering problems, leaving a gap between current learning outcomes and the desired standard for cultivating outstanding engineers.

Accordingly, the core issue this reform seeks to address can be summarized as follows: how to overcome students' difficulties in learning and applying course content, and how to help them develop engineering thinking and improve their ability to solve complex engineering problems through curriculum reform.

### *3.2 Reform Measures*

**Leveraging Online Resources for Personalized Learning**

Course content was streamlined to focus on **complex engineering problems** as the central theme, guided by a problem-posing and problem-solving approach that highlights core and challenging concepts. Using AI-assisted knowledge mapping on the online learning platform, a **hybrid online–offline teaching model** was implemented. Pre-class, in-class, and post-class content—including learning materials, self-study resources, feedback mechanisms, and learning checkpoints—was carefully designed to create a closed-loop learning environment that addresses the course's inherent difficulty while supporting **personalized, layered learning**.

The course is widely regarded as challenging due to its reliance on strong mathematical and engineering foundations and the extensive use of formulas across modules. Students who do not grasp the course structure and develop effective learning strategies early may feel overwhelmed. Therefore, the first step was to restructure content, simplify complex topics, clarify course objectives, and provide students with an early overview of the curriculum. Real-world engineering problems were used to introduce topics sequentially according to cognitive principles, guiding students to integrate knowledge through AI-generated knowledge maps and self-created mind maps. This approach effectively mitigates the course's perceived difficulty.

Integrating Eight Industrial Case Studies

High-quality case studies can enhance engagement, deepen understanding, and reduce learning difficulty. Eight representative industrial cases—such as ethanol fermentation, penicillin fermentation, citric acid production by *Aspergillus niger*, algal SCP production, PHA fermentation, and glucose-to-gluconic acid enzymatic production—were selected to connect the entire curriculum. These cases cover reaction kinetics, bioreaction process dynamics (including enzyme and microbial kinetics), and transport processes, with clear links between modules. Real-world cases allow students to simulate practical problem-solving strategies. Cases were chosen based on scientific validity, representativeness, richness, and extensibility. This "pearl-string" case-based approach not only reduces learning difficulty but also progressively develops students' engineering thinking and problem-solving skills.

**Introducing Practical Components**

Practical experience was incorporated through visits to operating bioreactors and pilot-scale facilities, as well as lectures delivered by industry mentors. Students gain first-hand industrial knowledge, particularly regarding reactor design, operation, scale-up, and troubleshooting. Additionally, large laboratory facilities, pilot plants, and collaborative enterprise resources provide authentic learning environments to enhance practical skills and experiential learning.

**Emphasizing Student-Centered Learning and Reforming Assessment**

The course redesign emphasizes student-centered learning and introduces a process-oriented assessment system. Guided by Outcome-Based Education (OBE) principles, a multi-dimensional hybrid teaching approach was adopted. Online resources provide just-in-time support for prerequisite knowledge in mathematics, microbiology, chemical engineering, and biochemistry. In-class activities employ flipped classroom and discussion-based methods, emphasizing key concepts while engaging students as active participants. Case studies are deconstructed during discussions, further expanded in post-class activities, and integrated across modules to help students build a coherent knowledge system. Assessments include differentiated tasks, encouraging students to tackle more challenging assignments and enhancing both engagement and the level of challenge.

For instance, in the enzyme kinetics module, students are provided with pre-class materials on the Michaelis-Menten equation and its derivation, previously covered in the biochemistry course. Pre-class assignments ensure that students have mastered the fundamental principles and formula derivations before attending lectures. During class, instruction focuses on the underlying concepts behind the equations, including key assumptions, the rationale for parameter simplifications, and parameters relevant to industrial applications, such as enzyme concentration. Cases involving substrate inhibition are introduced to illustrate derivation processes and facilitate comparative analysis, enabling students to gain a deep understanding of inhibitory regulation in bioreactions and the role of mathematics in modeling these processes.

Discussions may further extend to reversible reactions and allosteric regulation, while subsequent modules revisit these concepts within structured kinetic models that describe the effects of substrates on cellular responses. Post-class case studies reinforce that cellular responses are not only regulated at the level of local enzyme reactions but can also be globally regulated, such as the distinctions between balanced and unbalanced cell growth, and the modulation of metabolite production rates by specific growth rates and cell density. This case-based approach encourages students to transfer knowledge to new scenarios, fostering a deeper and more integrated understanding of enzyme kinetics.

**Strengthening Integration Across Engineering Course Clusters**

The engineering course cluster is centered on Fermentation Engineering, with *Bioreaction Engineering* as an upstream course and *Bioprocess Equipment* and *Enzyme Engineering* as downstream courses. This course emphasizes cross-course integration, optimizes module content, reduces redundancy in instruction, and enables case-sharing across courses, thereby enhancing curriculum coherence and overall learning effectiveness.

## IV. CONCLUSIONS AND RECOMMENDATIONS

The reform results demonstrate that this approach has effectively increased students' engagement and significantly enhanced the development of engineering thinking. Students' ability to analyze and solve complex engineering problems has improved markedly. Additionally, students actively participated in the innovation and entrepreneurship activities associated with the subsequent course, achieving both a higher number and greater level of awards. Overall, this reform offers a scalable and transferable teaching model for cultivating outstanding engineers.

## ACKNOWLEDGEMENT

We gratefully acknowledge the financial support provided by the Dalian University Teaching Reform Project (2024152) and the Undergraduate Innovation and Entrepreneurship Program(202411258009).

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