Study on the Teaching Reform of *Gene Engineering Principles*

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Abstract *Gene Engineering Principles* is a fundamental professional course for majors such as bioengineering and biotechnology. It integrates theoretical knowledge with experimental practice and engineering applications. It is characterized by its comprehensive and highly practical nature. Aligning with the new-era higher education philosophy of 'competency-oriented, value-driven' teaching, this study presented a systematic exploration and practice based on undergraduate cohorts from 2018 to 2020 in Chengdu University. The reform focused on teaching methodology, formative assessment, and the integration of ideological and political education. Key strategies included the introduction of classical experimental cases, emphasis on pre-class preparation, enhancement of classroom interaction, focus on engineering-oriented applications, optimization of assessment mechanisms, and the incorporation of national strategic needs into the curriculum. These measures effectively stimulated students' learning motivation and research potential, thereby improving the overall teaching quality and educational effectiveness of the course. The results of the teaching reform demonstrate significant improvements in students' ability to apply theoretical knowledge to practical engineering problems, scientific thinking, experimental research skills, scientific reasoning, and professional identity. Reformed classes outperformed control groups across various instructional metrics, achieving notable educational outcomes.

Key words *Gene Engineering Principles*; Teaching reform; Experimental teaching; Curriculum ideology and politics; Competency-oriented; Diversified assessment

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With the rapid development of life sciences and biotechnology, genetic engineering has emerged as a core supporting technology. It is widely applied in medicine, agriculture, environmental protection, and other fields, becoming a key driver of the national bioeconomy[1 – 2]. As an essential foundational course for undergraduate education in biological sciences, *Gene Engineering Principles* not only fulfills the teaching objectives of knowledge dissemination and skill training but also shoulders the educational mission of cultivating students' scientific literacy, engineering thinking, and social responsibility[3 – 4]. However, long-standing issues persist in the teaching practice of this course. First, the teaching methods remain relatively monotonous, primarily relying on the traditional spoon-feeding approach characterized by 'teacher lectures, students listen', resulting in insufficient student initiative and low classroom engagement. Second, there is a disconnect between experimental and theoretical instruction, due to the lack of problem-oriented and research-driven guidance, making it difficult for students to effectively apply acquired knowledge to practice, particularly in engineering applications. Third, the assessment methods are overly outcome-oriented, neglecting the evaluation of students' skills for core genetic engineering experiments, logical thinking, and innovative awareness. Fourth, the course lacks strong value-oriented guidance, failing to fully reflect the fundamental mission of 'fostering virtue through education' in higher education in the new era[6 – 7].

To effectively address these issues and implement the Ministry of Education's overarching requirements for 'curriculum ideological and political education' and 'new engineering education', the teaching team conducted systematic reforms targeting undergraduate students majoring in bioengineering in Chengdu University (2018 – 2020 cohorts). The reforms focused on four key dimensions: optimizing teaching content, innovating instructional methods, improving assessment systems, and integrating ideological and political education into the curriculum. We systematically guided students to address national needs and ethical issues in biotechnology development by introducing classic experimental cases, combining pre-class preparation with in-class interaction, emphasizing key/difficult concepts and engineering applications, strengthening standardized experimental procedures and report-writing training, and establishing a dual-focus assessment mechanism valuing both process and results. This approach progressively established a competency-enhancing and value-oriented teaching framework. This paper systematically summarized the teaching reform approaches, implementation strategies, and practical outcomes of the *Genetic Engineering Principles* course, aiming to provide transferable experience for the reform and optimization of similar courses.

Basic Ideas for the Teaching Reform

Genetic Engineering Principles is a core course integrating theory, experiments, and engineering, serving as a crucial component for students in bioengineering and biotechnology to master modern molecular biotechnology and understand life engineering application principles. The curriculum content covers key technologies such as gene isolation, recombination, expression, and regulation, spanning multiple disciplines including molecular biology, cell biology, biochemistry, and microbiology. It is characterized by

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broad content coverage, rapid technological advancements, and high practical demands[6-8]. However, in traditional teaching practices, this course still faces several areas requiring improvement. The main issues include: a predominantly lecture-based teaching approach lacking inspiration and interaction, disconnection between theoretical and experimental content, insufficient practical application, student learning being exam-oriented without active knowledge construction and deep understanding, over-reliance on experimental results and report writing in the evaluation system while neglecting process management and skill development, and the absence of ideological and political elements in the curriculum. As a result, it fails to achieve the integration of 'educating people' and 'nurturing talents'.

To address these issues, the curriculum reform must start from the fundamental teaching concept and reconstruct the teaching system and methods. This reform adhered to a student-centered, competency-oriented, and value-guided teaching approach, and established curriculum objectives focusing on enhancing students' research capabilities, engineering literacy, and social responsibility. The reform was advanced through three key aspects: diversification of teaching methods, optimization of curriculum process management and assessment mechanisms, and integration of ideological and political education with national strategies. First, from the prespective of diversification of teaching methods, the curriculum design emphasized the integration of theoretical instruction with experimental practice, combined classroom teaching with case-based learning, and balanced individual study with group discussions. It strived to shift from the 'teacher-centered' approach to a 'student-centered' one, fostering students' initiative and engagement in learning. Throught the incorporation of classic experimental cases, flipped classrooms, and problem-driven learning, the reform aimed to enhance students' inquiry skills and critical thinking ability. Second, for the optimization of curriculum process management and assessment mechanisms, moving away from the traditional single-evaluation approach based solely on attendance and exams, a comprehensive process-based evaluation system was established. This system incorporates attendance performance, pre-class preparation, in-class discussions, post-class summaries, engagement with cutting-edge developments, and final assessments. It focuses not only on 'what is learned' but also on 'how can students learn it' 'whether critical thinking is applied', and 'whether it can be applied'. Through meticulous process management, a multidimensional evaluation of students' comprehensive ability can be achieved. Third, in terms of the integration of ideological and political education with national strategies, the curriculum incorporates elements such as scientific ethics, national biosecurity, and industrial transformation cases, guiding students to understand the value and significance of their knowledge from the perspective of national development and public health. Students will recognize biotechnology not just as 'laboratory techniques' but as 'technology serving the people' by highlighting China's major advancements in biopharmaceuticals, vaccine development, agricultural breeding, and related fields. This approach aims to inspire their sense of national responsibility and mission.

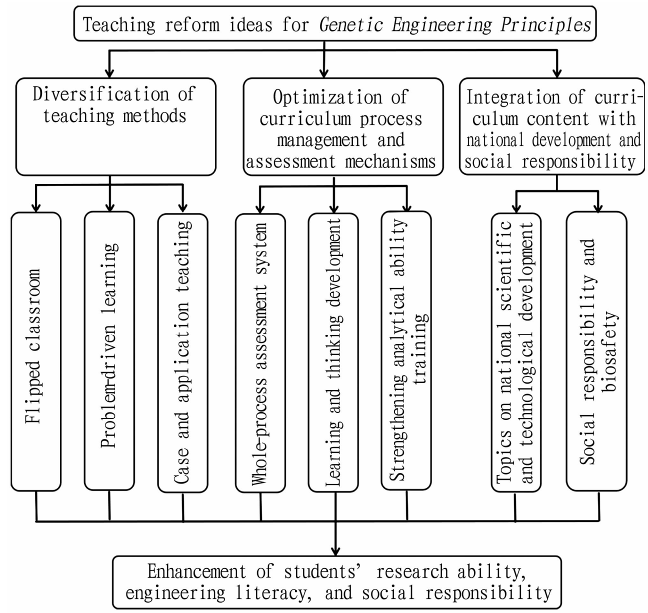

Fig. 1 Reform strategy of laboratory teaching of *Gene Engineering Principles*

Key Points of Teaching Reform

Upholding the student-centered approach and advancing the flipped classroom model

The traditional teacher-centered lecture model faces limitations such as constrained class time, passive knowledge absorption by students, and a lack of in-depth thinking and hands-on practice. To address these issues, we focused on enhancing students' self-directed learning ability and classroom engagement by actively promoting the flipped classroom model. This reform aimed to deeply integrate teaching concepts with methods, ensuring students gain a solid understanding and practical application of core theories and techniques in genetic engineering. The core concept involves shifting knowledge delivery from traditional in-class lectures to pre-class preparation, providing students with systematic and concise learning resources such as carefully designed micro-lession videos, teaching PPT, and guided literature readings. Classroom time is then dedicated to problem-oriented group discussions, case analyses, and simulated experimental design. The case studies primarily draw from real-world research projects and industrial applications in genetic engineering, such as vector optimization in recombinant protein expression, primer and PCR program design, and target selection for CRISPR systems. Teachers guide students to raise questions, design experimental protocols, and anticipate technical challenges based on case studies, fostering active inquiry and critical thinking. In the classroom, instructors transition from being 'knowledge transmitters' to 'learning facilitators' and 'thought stimulators', sparking students' innovative potential through dynamic questioning and diverse discussion manners.

The research team found that the quality of classroom discussions is directly influenced by students' autonomy and depth of pre-class learning. Some students, due to insufficient motivation or weak foundational knowledge, often come to insufficient preview, which limits the effectiveness of classroom interactions. To address this, the teaching team implemented multiple incentive measures, including incorporating pre-class preparation into regular grading, assigning clear responsibilities in group learning tasks, and providing timely teacher feedback on preparatory work. These measures established a positive cycle of 'pre-class preparation, in-class participation, and post-class reflection'. Meanwhile, we offered online Q&A sessions to help students overcome difficulties in pre-class learning. The effectiveness of this teaching reform has been validated through multi-dimensional evaluations. Final exam results showed that students in flipped classrooms demonstrated significantly better mastery of theoretical knowledge and experimental design skills compared with those in traditional teaching models. According to course satisfaction surveys, approximately 96% of students acknowledged that the flipped classroom enhanced their self-directed learning and problem-solving abiliy, while also finding classroom interactions and hands-on sessions more engaging. The flipped classroom model, as a key breakthrough in the teaching reform of the Genetic Engineering Principles course, has not only effectively addressed the 'dual-core' challenge of knowledge delivery and skill development in traditional teaching but has also fostered students' self-directed learning habits and innovative thinking. This approach lays a solid foundation for building a high-level application-oriented talent cultivation system in life sciences.

Building knowledge systems around real-world problems to enhance problem-solving skills

In the course teaching reform, problem-driven learning was adopted as one of the core teaching strategies to effectively break students' passive learning habits and fragmented understanding. Given the course's complex technical system, interdisciplinary knowledge integration, and emphasis on innovation, the teaching approach prioritizes comprehensiveness, inspiration, and engineering orientation. In practice, we designed a series of authentic or simulated problems closely aligned with the course content based on teaching progress. For example, in the 'Recombinant Plasmid Construction' chapter, we presented a problem scenario: 'A biotech company aims to express a high-efficiency recombinant protein. Please design a suitable expression system for them and evaluate the feasibility and production efficiency of the technical approach.' Students were required to propose scientifically sound solutions through comprehensive analysis of factors such as promoter selection, tag design, vector type, and host systems. Throughout this process, students must review extensive literature, compare the pros and cons of different technical approaches, engage in team discussions, and conduct preliminary validation through experiments or computational tools. This approach not only deepened their understanding of specialized knowledge but also trained their logical thinking and communication skills.

Students not only consolidate theoretical knowledge but also enhance their understanding of technical ethics, safety protocols, and societal impacts by solving diverse complex problems, which is of great significance for implementing ideological education and engineering ethics in the curriculum. To ensure the effective implementation of problem-driven teaching, scientific arrangements must be made in instructional design, problem formulation, and process organization. The problems must be open-ended, relevant, and challenging. They should align with students' existing knowledge while stimulating their interest and motivation for further learning. As instructors, we must strike a balance between guidance and autonomy: neither completing tasks for students nor leaving them without direction, but rather providing targeted guidance and cognitive training at critical junctures. The integration of formative assessment facilitates the evaluation of students' information retrieval skills, teamwork performance, and innovative thinking during the problem-solving process, effectively achieving the teaching outcome of 'tailoring instruction to learning needs and enhancing learning through practice'.

Emphasizing classic cases and their application in teaching and accurately buidling a bridge between theory and reality

As a highly engineered and industrialized system of life science technologies, this course has accumulated a wealth of representative, exemplary, and pioneering technical cases throughout its development. These cases not only embody rich academic principles and technical details but also profoundly demonstrate the practical application value of biotechnology in fields such as medicine, agriculture, and environmental protection. Organically integrating classic cases into teaching content, we can effectively bridge the gap between theoretical learning and the real world, enhancing students' knowledge transfer ability, engineering design awareness, and systemic cognitive skills. In the curriculum design, we carefully selected a number of representative engineering cases aligned with the teaching content and schedule, embedding them throughout various knowledge modules. For example, when teaching 'recombinant protein expression technology', we introduced cases such as insulin synthesis and interferon expression, thoroughly analyzing the entire process from gene design, vector construction, host selection to expression optimization. Through the study and analysis of these cases, students could not only clarify the causal relationships between technical approaches and experimental parameters but also understand real-world engineering challenges such as expression efficiency, protein activity, and downstream processing difficulties. This enhances their ability to evaluate technologies and solve practical problems.

In the 'Applications of Recombinant DNA Technology' module, we introduced classic cases such as 'gene therapy for human β-thalassemia', 'the commercialization process of transgenic Bt cotton', and 'CAR-T cell therapy applications'. These enable students to gain an in-depth understanding of genome editing logic in different fields. Through study of these cases, students can develop a cognitive framework spanning from molecular-level design to system-level implementation, better mastering cross-scale multistage engineering thinking. Meanwhile, classroom discussions are supplemented with case-based tasks that guide students to debate and explore issues such as 'balancing technical efficiency with ethical risks' and 'comparing the merits of different technical solutions.' These activities enhance students' critical thinking and comprehensive communication skills. Such tasks effectively improve students' ability in information integration, experimental design, and applied innovation, transforming them from 'knowledge recipients' into 'technology creators'. The effective implementation of case-based teaching relies not only on the quality of selected cases but also on instructors' ability to facilitate problem-oriented analysis and systematic deconstruction. Teachers should possess the 'deconstructing-reconstructing-guiding' pedagogical competency. That is to say, they should be capable of extracting key issues from cases, clarifying the logical relationships between technical principles and engineering links, and transforming them into thought-provoking teaching resources. Through this series of teaching designs and implementations, we achieve the transition 'from knowledge to competence, from understanding to application', laying a solid foundation for students' future development in diverse paths such as scientific research, industry, or public governance.

Implementing comprehensive assessment methods to build an evaluation mechanism that promotes learning and ability development

The reconstruction of assessment mechanisms is not only a crucial component of teaching quality assurance but also a core driver for enhancing students' comprehensive ability, guiding the transformation of learning approaches, and achieving course objectives. In traditional models, curriculum assessments often focus on testing knowledge retention and comprehension through final exams, leading students to adopt 'exam-oriented learning' while neglecting the systematic development of skills, competencies, and thinking methodologies during the learning process. To address this challenge, we established a comprehensive assessment system centered on 'embedded throughout the process, multi-dimensional coordination' in our teaching practice. This system aimed to stimulate students' learning initiative and enhance their practical skills and problem-solving awareness through a full-process evaluation mechanism. This assessment system was designed to integrate with multiple teaching modules of the course, covering various components such as pre-class preparation, in-class performance, phased tasks, course papers, and final exams. It incorporates evaluation indicators including knowledge mastery, research skills, thinking quality, and engineering awareness (Table 1).

Table 1 Grades component of course assessment %

Project	Attendance	Preview situation	Group discussion	Stage tasks	Course paper	Exam results
Reform class	10	10	10	10	10	50
Control class	40	–	–	–	–	60

In the pre-class phase, we designed preparatory assignments incorporating literature reading, guided quizzes, and knowledge mapping aligned with the teaching content. For instance, before covering the 'gene expression regulation' module, students were required to review recent five-year research advances in promoter optimization strategies and submit summarized mind maps to the learning platform. This approach not only develops students' information retrieval and synthesis skills but also establishes a cognitive foundation for in-class learning. This task accounts for part of the regular assessment score, effectively shifting students from 'passive listening in class' to 'active thinking before class'. During classroom sessions, a dynamic evaluation approach is adopted, utilizing indicators such as attendance check-ins, group discussion records, case analysis scores, and task completion quality to monitor students' engagement levels and interaction performance in real time. For example, in the 'Gene Cloning' module, instructors designed a plant-based simulation task requiring students to form teams and develop an integrated gene cloning and transgenic application plan on the spot. This comprehensive assignment covered primer design, PCR programming, gel electrophoresis, sequencing analysis, vector construction/selection, *Agrobacterium* application, and transgenic procedures, systematically demonstrating the train of thought. The evaluation criteria encompass not only technical feasibility but also logical presentation, teamwork efficiency, and defense performance. This assessment approach oriented by 'problem-analysis-reflection' encourages students to view experimental processes as scientific exploration rather than rigid procedural execution. The course's later-stage assessments emphasize cross-module knowledge integration and practical skill application. Students are required to submit a course thesis or present a genetic engineering design project, proposing technical solutions based on real-world needs. For instance, one student selected 'Plant-Based Vaccine Vector Development' as his or her topic, constructing a comprehensive expression system design roadmap supported by recent research findings for feasibility demonstration. Instructors evaluated the work based on technical depth, innovative thinking, and logical presentation, while peer-review sessions following the presentation strengthened students' critical thinking and multi-dimensional evaluation consiciousness. Through systematic integration and flexible implementation of the comprehensive assessment approach, students evolve from passive 'outcome recipients' to proactive 'competency builders', achieving a more effective transition from knowledge acquisition to comprehensive skill enhancement. Teaching practice demonstrates that this assessment mechanism effectively facilitates the transformation of students' learning approaches, strengthens the practical relevance of course content, and enhances educational motivation, providing robust support for building a high-quality sustainable education system of life science engineering.

Optimizing instructional guidance based on cognitive structures to facilitate knowledge reconstruction and scientific thinking development

As an interdisciplinary course integrating biology, engineering, and information technology, this course requires students not only to master theoretical knowledge and technical operations but also emphasize the systematic development of their learning approaches and thinking ability. We believe that the enhancement of learning and thinking constitutes a critical component in cultivating innovative bioengineering talents. Therefore, in our teaching reform, we established the dual objectives of optimizing learning methods and training thinking skills, while exploring student-centered diversified teaching strategies. In terms of learning approaches, the reform emphasized guiding students' transition from passive reception to active construction, with a focus on cultivating the competency of 'learning to learn'. Specifically, we implemented a blended model combining differentiated instruction and self-directed learning, encouraging students to select appropriate learning paths and resources based on their individual foundations. Particular support was provided for students to utilize the university's Chaoxing teaching system, library resources, and key laboratory platforms (including coarse cereals processing, food processing, meat processing, medicinal food homology, and biomedicine). In the classroom, we placed greater emphasis on guiding students to summarize key knowledge points and training their logical expression and scientific argumentation skills to facilitate the internalization and transfer of learning content. We encouraged students to analyze problems from diverse perspectives, propose hypotheses and validate solutions by designing open-ended questions, interdisciplinary case studies, and simulated research projects. For example, in the 'Gene Expression Regulation' module, students were required to design gene regulatory network models, analyze the effects of different regulatory elements on expression levels, and explore the dynamic patterns of gene regulation. Such tasks demanded students to integrate molecular biology knowledge with mathematical modeling skills, honing their systems thinking and cross-disciplinary innovation ability. In practice, students generally reported that this integrated learning-and-thinking cultivation approach helped them overcome the challenge of fragmented knowledge while strengthening their holistic grasp of course content and application confidence. Meanwhile, we also noticed that students became more confident in group discussion and scientific research design, expressed themselves more clearly, and put forward constructive suggestions on their own initiative, showing good thinking quality.

Emphasizing key/difficult concepts and engineering application analysis to enhance learning depth

The genetic engineering course encompasses extensive knowledge coverage, abstract concepts, and complex technical details, often leading students to encounter comprehension difficulties and application barriers. To address this challenge, our teaching reform strengthened the explanation of key and difficult concepts, with particular focus on their engineering applications, helping students achieve 'deep mastery' rather than 'superficial memorization' of knowledge. First, in selecting teaching content, instructors strategically identified key knowledge points critical to experimental success, including vector design (promoters, selectable markers, replication origins), restriction enzyme recognition site arrangement and compatibility, expression system optimization (*e. g.*, lac, T7 systems), and target protein purification/detection strategies. Each component was supported by logical diagrams, flowcharts, and video animations to help students build knowledge frameworks and clarify technical principles and operational significance. Second, instructors strengthened the connection between knowledge and practical engineering through a 'theory + application' approach. For instance, when teaching gene expression regulation, case studies of high-efficiency vaccine antigen protein production were introduced; vector selection principles for industrial fermentation systems were explained during plasmid design modules; and CRISPR technology applications in crop improvement were incorporated when covering gene editing content. Through these vivid cases, students not only grasped the principles but also understood their real-world significance and technical value. Additionally, the course incorporated 'engineering challenge questions' such as 'How can we express a strongly hydrophobic foreign protein in Escherichia coli?' and 'How can we complete recombination when restriction enzyme sites are missing?' These prompts encouraged interdisciplinary thinking, guiding students to design solutions using acquired knowledge. This training approach can strengthen students' engineering design awareness and technical adaptability. To cultivate practical engineering perspectives, some curriculum content adopted a 'modular design thinking' approach, encouraging students to complete small-scale experimental designs (*e. g.*, vector construction proposals) in project teams, followed by inter-group presentations and defenses for developing their logical communication and project reporting skills. The course achieves the transformation from 'mastering knowledge points to solving practical problems' by integrating focused key-concept instruction with engineering-oriented design, significantly enhancing students' technical comprehension depth and application capabilities. This provides strong support for their future endeavors in research, industry, or advanced studies.

Deeply integrating ideological and political education into the curriculum to cultivate social responsibility

Against the background of intensifying global technological competition and biotechnology's profound impact on national strategic security and public health, incorporating ideological and political education into specialized courses has become a crucial task in higher education reform. As a vital bridge connecting fundamental science with industrial practice, this course inherently embodies multiple dimensions of 'technology + ethics + national mission,' making it an ideal vehicle for ideological and political education. In our teaching reform, we organically integrated these elements into knowledge teaching rather than employing 'rigid indoctrination', achieving subtle yet effective value guidance.

For example, when introducing vaccine expression systems, we highlighted China's breakthroughs in self-developed mRNA and recombinant protein COVID-19 vaccines, helping students recognize biotechnology's critical role in pandemic response. During gene editing instruction, we facilitated discussions on ethical boundaries and societal impacts regarding animal genetic modification and transgenic crop breeding. Additionally, the course incorporated a 'National Strategic Needs' module, introducing key initiatives from China's 14^{th} Five-Year Plan regarding bioeconomy, synthetic biology, and biosecurity. This helped students understand their discipline's profound connection to national development, inspiring patriotic commitment. Teaching cases frequently highlighted Chinese scientists' technological contributions in agricultural breeding, medical diagnostics, and environmental remediation (*e. g.*, Yuan Longping, and Tu Youyou), motivating students to pursue scientific careers with ethical responsibility. The assessment system included 'Science & Ethics' thematic essays, encouraging students to analyze biotechnologies' societal impacts and policy implications from multiple perspectives, cultivating multidimensional thinking and public communication skills.

This ‘knowledge-values-responsibility’ integrated approach not only enables students to master technical skills, but also establishes a modern scientific research consciousness of serving the country through science and technology, serving the society, making rational judgments and complying ethics, which provides a solid ideological foundation for them to move towards the academic frontier or the front line of industry in the future.

Table 2 Teaching reform effects of the *Genetic Engineering Principles* course %

Class	Pass rate	Excellent rate	Curriculum satisfaction
Bioengineering 18 – 1 (reform class)	96.00	32.00	96.00
Bioengineering 18 – 2 (control class)	88.89	18.52	92.59
Bioengineering 19 – 1 (reform class)	95.83	29.17	95.83
Bioengineering 19 – 2 (control class)	91.30	26.09	91.30
Bioengineering 20 – 1 (reform class)	92.00	28.00	96.00
Bioengineering 20 – 2 (control class)	89.29	21.43	92.86

Effects of the Teaching Reform

As a core fundamental course for life science majors, *Genetic Engineering Principles* directly impacts students' comprehension and mastery of related subjects like genetics and specialized experiments, while serving as a crucial component for developing their research literacy and innovation capability. In recent years, addressing issues such as outdated content systems, monotonous teaching methods, and low student engagement, we have implemented comprehensive teaching reforms including modular curriculum restructuring, flipped classroom approaches, blended online-offline instruction, and competency-oriented diversified evaluation systems. Since implementation, our bioengineering students have demonstrated significant improvements in theoretical knowledge mastery, research awareness, experimental skills, and social responsibility consciousness (Table 2). Classroom interactions have significantly increased, with students demonstrating deeper content understanding and markedly enhanced learning motivation and active participation. Although the reform is ongoing, practice demonstrates that student-centered teaching innovation effectively enhances course quality and promotes holistic development, offering a valuable model for high-quality undergraduate education.

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