Practical Teaching Reform of Bioengineering for Competency Enhancement: Research on Low-cost and High-efficiency Teaching Mode Based on Video Resources

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Abstract Under the background of competency-based transformation of higher education, bioengineering major urgently needs to solve the problems such as the disconnect between practical teaching and industry needs and the lack of resources. This paper proposed supplementing traditional experimental teaching with video resources to construct a closed-loop model of "theoretical instruction, case analysis, video demonstration, and reflective application". Through the development of instructional videos covering core techniques such as PCR, Western blot, CRISPR-Cas9, cell culture, HPLC, GMP operations, and bioinformatics analysis, teaching costs can be reduced, spatiotemporal constraints can be overcome, and process visualization can be enhanced, thereby supporting students in mastering the entire workflow of modern biomanufacturing. The paper further explored resource development pathways, university-enterprise collaboration mechanisms, and curriculum integration strategies, offering actionable solutions for practical teaching reform.

Key words Bioengineering; Practical teaching; Competency development; Video resources; Teaching reform; Industry-education integration

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With the incorporation of bioeconomy into the national strategy, the *Plan for Bioeconomic Development during the* 14^{th} *Five-Year Plan* explicitly proposes to accelerate the integration of biotechnology in fields such as medicine and agriculture, creating an urgent demand for high-quality engineering and technical talents[1]. As an engineering major, bioengineering should emphasize "engineering" and "practicality" in talent cultivation. The *National Standards for Teaching Quality in Undergraduate Majors in General Higher Education Institutions* issued by the Ministry of Education requires that practical teaching accounts for no less than 25% of credits, aiming to develop students' ability to solve complex engineering problems[2].

However, the *2025 Chinese Undergraduate Employment Report* by the MyCOS Research Institute points out that although graduates majoring in bioengineering enjoy stable employment, their starting salary growth is slow, and career development paths remain unclear, rooted in the fact that "what they learn is not what they apply"[3]. Companies widely report that graduates exhibit shortcomings in experimental standards, process understanding, GMP awareness, and data analysis[4]. Meanwhile, universities are constrained by high laboratory costs, slow equipment upgrades, and limited internship opportunities, making it difficult for practical teaching to meet industry demands for "ready to fight" talents.

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In this context, exploring new low-cost and high-efficiency models for practical teaching has become imperative. In recent years, the rapid development of digital educational resources such as short videos, MOOCs and virtual simulations has provided new pathways for teaching reform. Video resources, with their intuitiveness, repeatability, and ease of dissemination, offer unique advantages in skills training. This study focused on "competency enhancement" and systematically explored the application pathways of video resources in practical teaching of bioengineering, aiming to provide viable solutions for addressing the challenge of "emphasizing theory over practice".

Core Challenges in Competency-oriented Practical Teaching of Bioengineering

Severe disconnect between practical teaching and industry competency requirements

There is a clear disconnect between current bioengineering practical teaching and the industry's demand for interdisciplinary talents. As biotechnology advances toward industrialization and engineering, corporate expectations for graduates have expanded from basic experimental operation to technology research and development, quality control, data analysis and project management[5]. However, universities still primarily focus on verification-based experiments such as DNA extraction and PCR amplification, while providing insufficient training in key techniques including qPCR, Western blot, CRISPR-Cas9, and mammalian cell culture, resulting in a "skills gap" after students enter enterprises. Modern biomanufacturing heavily relies on quality management systems such as GMP and GLP, yet related teaching remains largely theoretical, lacking practical operation and case training in real-world scenarios, making it difficult for students to develop a systematic understanding. In terms of data analysis, skills such as omics processing, BLAST alignment, primer design, and R/Python programming have become fundamental requirements for R&D positions. However, teaching in these areas often lacks integration and project-driven training. Engineering practices such as fermentation optimization, purification design and pilot-scale amplification and knowledge of drug registration regulations remain inadequately covered at the undergraduate level. Interdisciplinary tools such as AI-assisted design, literature mining, and image recognition, as well as soft skills such as technical documentation writing and teamwork, are increasingly critical in enterprises. However, these have not been effectively integrated into the teaching system. These issues highlight that educational objectives, content updates and implementation pathways lag behind industrial development, constraining graduates' career adaptability and competitiveness.

Insufficient investment in practical teaching resources due to high costs

Bioengineering experiments rely on expensive equipment (such as HPLC and bioreactors) and high-value consumables (such as cell culture media and chromatography columns), resulting in high per-use costs. Due to budget constraints, local universities often reduce experimental hours or simplify procedures, limiting students' hands-on opportunities. It is difficult to establish authentic production environments such as GMP workshops and pilot-scale platforms on campus, hindering students' understanding of the complete process chain. Furthermore, the depth of collaboration between universities and enterprises is insufficient. Although most universities have established internship bases, enterprises often restrict students to observational roles due to concerns about confidentiality, safety, and management costs, making it difficult for them to engage in core operational processes[6]. Even when granted access to clean areas, students are typically limited to observation and are unable to operate critical equipment or participate in quality management procedures such as batch record documentation and deviation handling. This results in "seeing without understanding, understanding without mastering", significantly undermining the effectiveness of internships and the transformation of knowledge into practical skills.

Insufficient depth in university-enterprise collaboration, limited exposure of students to real-life scenarios

Although most universities have established internship bases, enterprises often restrict student participation to observational roles due to concerns regarding technical confidentiality, production safety, and management costs. As a result, students rarely gain access to core production processes. Even when granted access to clean areas, students are limited to observation and cannot operate critical equipment or participate in quality management processes such as batch record documentation and deviation handling. It leads to a situation of "seeing without understanding, understanding without mastering", significantly undermining the effectiveness of internships and the transformation of knowledge into practical skills. Such superficial internship arrangements not only fail to help students develop systematic engineering thinking but also prevent them from fully understanding the standardized operational processes of modern biomanufacturing, thereby impacting their future career adaptability.

The Value and Advantages of Video Resources in Competency Development

Breaking spatiotemporal constraints to achieve "ubiquitous learning"

Video resources, accessible via online platforms, support pre-class preparation, in-class reference, and post-class review, overcoming the spatiotemporal limitations of traditional experimental teaching. Compared with static images or verbal explanations, videos can dynamically present complex experimental procedures and equipment operations, significantly enhancing visualization[7]. For example, through high-definition live footage or 3D animations, processes such as fluid mass transfer in fermenters, protein separation in chromatography columns, and Western blot membrane transfer electrophoresis can be clearly demonstrated, helping students gain an in-depth understanding of experimental principles and operational logic. Furthermore, the development and maintenance costs of videos are significantly lower than those of physical laboratories. A high-quality video can be used for multiple academic years with minimal marginal cost, making it particularly suitable for teaching high-cost techniques such as HPLC analysis, cell culture, and mass spectrometry.

Enhancing process visualization to improve comprehension depth

Many biological processes (such as fermentation kinetics, chromatographic separation, and lyophilization curves) are highly dynamic and microscopic in nature. Through high-definition live scenes or 3D animations, abstract concepts can be concretely visualized. For instance, a video demonstration of "antibody binding to Protein A ligands in affinity chromatography" is far superior to static diagrams. Additionally, videos can recreate real-world scenarios such as GMP workshops, pilot-scale platforms, and QC laboratories, enabling students to visually understand key procedures including clean area protocols, batch record documentation, and deviation handling, even when hands-on operation is not feasible. This approach helps bridge the practical gaps caused by insufficient university-enterprise collaboration.

Reducing teaching costs and improving resource reuse rate

The development and maintenance costs of video resources are significantly lower than those of physical laboratory construction. A high-quality instructional video can be used for teaching multiple cohorts of students over the long term, with marginal costs approaching zero. This is particularly suitable for teaching techniques involving expensive equipment and high consumable costs, such as HPLC analysis, cell culture, and mass spectrometry detection. Through systematic design, video resources can not only supplement theoretical teaching but also serve as a bridge connecting the classroom and the industry, effectively enhancing students' engineering cognition and career adaptability.

Supporting personalized and differentiated learning

Video resources enable students to selectively review content based on their individual weaknesses, such as repeatedly studying "Western Blot membrane transfer techniques" or "qPCR primer design principles", thereby achieving personalized learning paths. Students can be guided to transition from "passive watching" to "active thinking" by viewing tasks, knowledge point quizzes, and open-ended assignments, ensuring the effective integration of resources into the entire teaching process[8].

Design of Application Pathways for Video Resources

Constructing a "four-stage closed-loop" teaching model

It is recommended to establish a four-stage closed-loop teaching model comprising "theoretical instruction, case analysis, video demonstration, and reflective application". Teachers first systematically explain principles and standards, then deconstruct processes and analyze problems using enterprise cases, and dynamically demonstrate the entire operational procedure through videos. Finally, students are guided to reflect and apply their knowledge through tasks such as writing operational reports or simulating process optimization. Priority should be given to building a video resource library covering core competencies, including modules such as molecular biology (CRISPR-Cas9 editing, vector construction), cell and fermentation engineering (cell subculture, 5L fermenter monitoring), analytical testing (HPLC protein purity analysis, ELISA detection), quality management systems (GMP gowning, batch record documentation), and bioinformatics skills (Primer-BLAST primer design, R language plotting).

Systematic development of a core competency video resource library

Universities should collaborate with enterprises to prioritize the development of video resources in following areas: molecular and cellular techniques (CRISPR-Cas9 editing, cell thawing and subculturing), analytical testing (HPLC protein purity analysis, ELISA detection), process production (inoculation monitoring in 5L fermenters, ultrafiltration concentration), quality management (GMP gowning, batch record documentation), data analysis (Primer-BLAST design, R language plotting), and cutting-edge interdisciplinary technologies (AI literature retrieval, image recognition for colony counting). A university-enterprise collaboration mechanism should be established, where enterprises provide non-confidential production videos, SOP documents, and other materials, while universities take charge of editing, dubbing, and teaching processing, forming a collaborative development model of "enterprises providing materials, universities transforming them, and sharing achievements together".

Promoting collaborative resource development between universities and enterprises

A cooperation mechanism of "enterprises providing materials, universities processing them, and sharing achievements together" should be established. Enterprises can supply non-confidential production videos and SOP documents, while universities take responsibility for editing, dubbing, and producing instructional micro-videos (each 3 – 8 min in length), with clear labeling of knowledge points and competency objectives. This approach facilitates resource sharing and achieves a win-win effect.

Integration into course assessment and quality evaluation

Video-based learning is incorporated into the formative evaluation system through viewing tasks, knowledge point quizzes, and open-ended assignments. This approach guides students to transition from passive watching to active thinking, ensuring the effective integration of resources throughout the teaching process. For instance, assessment methods such as "watching videos and submitting notes on operation points" and "technical Q&A based on video content" are implemented to foster proactive learning and critical reflection among students.

Implementation safeguard mechanisms

Universities should strengthen top-level design by incorporating video resource development into the overall planning of "New Engineering" construction, first-class majors, or curriculum ideological and political education. Special funds should be established to support faculty teams in resource development and teaching research, ensuring the sustained progress of the project[9]. Through policy guidance and financial support, the effective development and widespread application of video resources can be promoted. Interdisciplinary teaching teams composed of professional teachers, educational technology experts and enterprise engineers should be formed.

Conclusions

The reform of practical teaching in bioengineering, aimed at enhancing competencies, must address industry demands and overcome resource constraints. As a low-cost and high-benefit teaching tool, video resources play a significant role in compensating for inadequate experimental conditions, enhancing process visualization, and expanding learning boundaries[10]. Through systematic planning, university-enterprise collaboration, and closed-loop design, the establishment of a competency-oriented video teaching approach not only enhances students' experimental skills, engineering thinking, and professional quality, but also provides a replicable and scalable solution for local universities to advance practical teaching reform under resource constraints. Future efforts could further explore the integration of video resources with virtual simulation and AR/VR technologies to build a more immersive and intelligent new ecosystem for practical teaching.

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