

# A Study on the Reform of Teaching Methods for the Course Biochemistry and Molecular Biology in the Digital and Intelligent Era

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## Abstract

In the biomedical engineering talent development system, biochemistry and molecular biology serve as core bridge courses connecting basic medical science with engineering technology; the quality of their instruction directly impacts students' professional competence and innovative capabilities. Addressing prominent issues in traditional teaching—such as difficulties in visualizing molecular mechanisms, delays in updating course content, and a lack of diversity in assessment methods—this paper proposes a reform plan for course instruction driven by digital and intelligent technologies. By developing digital resources such as a dynamic 3D molecular structure visualization library and a virtual simulation experiment platform, and by designing intelligent teaching models that incorporate AI-assisted personalized learning and real-time data feedback, this study innovates the use of blended virtual-physical experiments and bioinformatics tools to facilitate a transition from “knowledge transmission” to “competency development”. This research provides theoretical references and practical pathways for curriculum reform in pharmacy and biomedical engineering programs.

**Keywords:** Digital and intelligent education, biochemistry and molecular biology, pedagogical reform, virtual simulation, precision teaching

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## 1. Introduction

With the advent of the digital age, a new generation of information technologies—represented by big data, artificial intelligence, and virtual reality—is profoundly reshaping the landscape of education. Biochemistry and molecular biology are foundational disciplines that study the chemical composition, structural functions, and molecular mechanisms of living organisms, occupying a central position in the training system for biomedical engineering professionals (Silva, Cecilio et al. 2026). As a bridge course connecting basic medical science with engineering technology, this course not only provides students with the theoretical foundation for understanding the molecular mechanisms of life processes but also lays the necessary knowledge foundation for subsequent studies in specialized fields such as biomaterials, medical imaging, tissue engineering, and AI-assisted diagnosis (Nimesh 2025). Currently, the wave of digital and intelligent transformation presents a historic opportunity for curriculum reform in biochemistry and molecular biology: by using digital tools to overcome visualization challenges, leveraging intelligent technologies to achieve precision in teaching, and utilizing virtual simulation to expand the boundaries of laboratory instruction (Chen, Lei et al. 2025), we can construct a new student-centered, competency-based teaching model. Exploring pathways for curriculum and teaching method reform driven by digital and intelligent technologies holds significant theoretical value and practical significance for enhancing the quality of talent cultivation, advancing educational modernization, and promoting the high-quality development of the biomedical industry.

## 2. Definition and Characteristics of Digital-Intelligent Education

### 2.1 Definition of Digital-Intelligent Education

Digital-Intelligent Education represents the advanced form of the evolution from Digital Education to Intelligent Education; it is a fusion of “digital intelligence” and “artificial intelligence” (Guo, Feng et al. 2025). From a developmental perspective, educational informatization has undergone three major phases: The first phase was

“Computer-Assisted Instruction”, which focused on the digital presentation of instructional content; the second phase was “Internet Plus Education”, which emphasized the online sharing of educational resources and online learning; and the third phase, the current “Digital-Intelligent Education” phase, is characterized by the use of big data analysis and artificial intelligence technologies to achieve precision, personalization, and intelligence in the teaching process(Jiang, Ma et al. 2025, Zhong, Jiang et al. 2025).

## 2.2 Core Characteristics of Digital and Intelligent Education

### (1) The Concept of Data-Driven Precision Teaching

Data-driven approaches are a key feature that distinguishes digital and intelligent education from traditional education(Wang, Li et al. 2021, Wang, Li et al. 2026). Through diverse channels such as learning management systems (LMS), online platforms, and smart devices, data on student learning behaviors can be collected, including video viewing duration, time spent on specific knowledge points, exercise accuracy rates, frequency of discussion participation, and experimental operation trajectories. Based on this data, teachers can accurately identify students’ learning difficulties, cognitive styles, and ability levels, thereby implementing differentiated instructional interventions. For example, by analyzing student exercise data from the “Enzyme Kinetics” chapter, the system can automatically assess their understanding of the Michaelis-Menten equation and push targeted supplementary materials or modified exercises. Data-driven precision teaching breaks away from the traditional “one-size-fits-all” teaching model, turning “teaching tailored to individual needs” from an ideal into reality.

### (2) Principles of Instructional Design for Interdisciplinary Integration in Biomedical Engineering

Biomedical engineering is a quintessential interdisciplinary field, encompassing multiple disciplines such as biology, medicine, engineering, and information science. Digital and intelligent education provides the technological foundation for this integration: on the one hand, tools and methods from emerging fields like bioinformatics and computational biology can be directly integrated into the teaching process(Zhang 2022), allowing students to engage with cutting-edge research early on; on the other hand, the cultivation of engineering thinking can be achieved through digital project-based learning(Zhang, Wen et al. 2022, Wang, Li et al. 2026). In instructional design, the principles of “problem-oriented, project-based, and data-driven” should be followed to break down disciplinary barriers, integrate knowledge modules, and cultivate students’ systematic thinking and innovative abilities. For example, when teaching “Protein Structure and Function,” molecular docking software can be introduced to allow students to predict drug-target interactions, thereby organically combining biochemical knowledge with drug design practice.

## 3. Current Challenges in Teaching Biochemistry and Molecular Biology

With the rapid advancement of biomedical technologies, traditional teaching models are no longer sufficient to meet the demands of talent development in the new era(Amor, Attanayake et al. 2020, Fan, Huang et al. 2023). On the one hand, cutting-edge developments in molecular biology are evolving at a rapid pace, with new technologies such as CRISPR gene editing, single-cell sequencing, and spatial transcriptomics continuously emerging. However, traditional textbooks have long update cycles and relatively static content, leading to a disconnect between classroom instruction and the latest advancements in the field(Gomez 2020); On the other hand, the research subjects in biochemistry and molecular biology are predominantly microscopic molecules. Core mechanisms such as DNA replication, protein folding, and signal transduction are highly abstract and dynamic, making it difficult for students to develop intuitive spatial understanding through traditional static diagrams and textual descriptions. Furthermore, traditional assessment methods emphasize rote memorization while neglecting the cultivation of scientific thinking, innovative abilities, and practical skills, making it difficult to effectively evaluate the development of students’ higher-order competencies.

### 3.1 Challenges in the Presentation of Teaching Content: Difficulties in Visualizing Molecular Mechanisms

The core subjects of biochemistry and molecular biology are biomacromolecules and their interactions. These microscopic processes exhibit spatial characteristics at the nanoscale and temporal dynamics on the millisecond scale, far exceeding the range of human direct perception. Traditional teaching primarily relies on static images, textual descriptions, and two-dimensional animations, making it difficult to realistically depict the three-dimensional structures, conformational changes, and dynamic processes of molecular machines(Gomez 2020, Yang 2020). For example, DNA replication involves the coordinated action of multiple proteins, such as helicases, primases, and DNA polymerases, and its spatiotemporal dynamics are extremely complex; the evolution of protein folding from primary to tertiary structure involves numerous intermediate states and changes

in the energy landscape. Students often resort to rote memorization to cope with these abstract concepts, making it difficult for them to establish a genuine understanding at the molecular level, let alone gain a deep understanding of the relationship between structure and function.

Furthermore, the network characteristics of metabolic pathways, the cascade amplification effects of signal transduction, and the regulatory mechanisms of gene expression all require dynamic visualization at the systems level. In traditional teaching, instructors typically use PowerPoint presentations to display static pathway diagrams, making it difficult for students to grasp the dynamic changes in metabolic flux, the real-time responses of feedback regulation, and the complexity of cross-talk between multiple pathways. This “visualization deficit” severely limits students’ deep understanding of core concepts and also impacts their learning outcomes in subsequent specialized courses.

### *3.2 Lag in the Update of Teaching Resources: The Discrepancy Between Rapidly Evolving Course Content and Outdated Textbooks*

Molecular biology is one of the fastest-developing fields in contemporary life sciences. Over the past decade, CRISPR-Cas9 gene editing technology has progressed from discovery to widespread application in just a few years, while single-cell sequencing technology has ushered life science research into the era of single-cell resolution. These breakthroughs have not only updated disciplinary knowledge but have also transformed research paradigms and technical approaches (Fan, Huang et al. 2023). However, the typical publication cycle for traditional textbooks is 2–3 years. Combined with the time lags associated with curriculum revisions and adjustments to instructors’ lesson plans, there is often a 5–10-year gap between classroom content and the cutting edge of the discipline. Taking gene editing technology as an example, most textbooks still primarily cover zinc finger nucleases and transcription activator-like effector nucleases, while coverage of the CRISPR system lags behind; In the section on protein structure, traditional textbooks focus on X-ray crystallography and nuclear magnetic resonance techniques, with insufficient coverage of cryo-electron microscopy (cryo-EM) and no mention of new advancements in AI-driven protein structure prediction. This lag results in students acquiring knowledge that is “outdated upon graduation,” making it difficult for them to adapt to the rapidly evolving research and industrial environments.

### *3.3 Limitations in Teaching Evaluation: Monotonous Assessment Methods Make It Difficult to Evaluate Higher-Order Skills*

Traditional assessment primarily relies on end-of-term closed-book exams, a method with clear limitations: first, it fails to effectively evaluate students’ scientific thinking skills, such as hypothesis formulation, experimental design, and data analysis; second, it overlooks the learning process, failing to reflect students’ engagement, progress, and collaborative abilities (Wang, Tian et al. 2022). More importantly, biomedical engineering emphasizes innovation and interdisciplinary integration—higher-order skills that are difficult to assess through paper-and-pencil tests (Ji, Zhu et al. 2023). For example, students may be required to design a plan for producing therapeutic proteins using genetic engineering techniques, involving multiple stages such as vector selection, optimization of expression systems, and formulation of purification strategies, which necessitates the comprehensive application of knowledge in biochemistry, molecular biology, and bioprocess engineering. Such comprehensive, open-ended tasks require diverse assessment methods, including formative assessment, authentic assessment, and portfolio assessment, which the traditional assessment system is clearly ill-equipped to handle.

## **4. Proposal for a Digital and Data-Driven Teaching Reform Plan**

Combining the characteristics of digital and intelligence-driven education with the current state of teaching in the “Biochemistry and Molecular Biology” course, and grounded in the talent needs of the biopharmaceutical industry, this paper proposes a systematic digital and intelligence-driven teaching reform plan. It constructs a new teaching system across three dimensions: the development of digital resources, innovation in intelligent teaching models, and reform of laboratory instruction.

### *4.1 Development of Digital Resources*

#### (1) Dynamic 3D Molecular Structure Visualization Library

A 3D molecular structure database covering the core content of the course will be established. This will include

high-resolution 3D structures of biomacromolecules such as proteins, nucleic acids, carbohydrates, and lipids, as well as dynamic simulations of key processes such as DNA replication, transcription, translation, and signal transduction (Chen, Zhang et al. 2024). This database should possess the following characteristics: First, high fidelity, utilizing experimental structural data from authoritative databases such as the Protein Data Bank (PDB) and employing molecular dynamics simulation techniques to depict conformational changes; second, strong interactivity, allowing students to freely rotate, zoom, and slice molecular models to observe the spatial positions of specific amino acid residues; and third, multi-scale capability, enabling cross-scale visualization ranging from atomic-level chemical bonds to cellular-level molecular machines.

#### (2) Virtual Simulation Experiment Platform

In response to the characteristics of molecular biology experiments—namely, high costs, long durations, and significant risks—a virtual simulation experiment platform has been developed to cover core experimental techniques such as gene cloning, PCR amplification, DNA electrophoresis, Western blotting, and cell culture. Virtual experiments should possess the following functions: First, end-to-end simulation, which fully replicates the real experimental process from reagent preparation and instrument operation to result analysis; Second, error tolerance and correction, allowing students to attempt incorrect operations (such as errors in PCR primer design or improper electrophoresis voltage settings), observe abnormal results, and analyze the causes; third, scenario diversification, providing variant experiments for different application scenarios, such as site-directed mutagenesis, vector construction, and expression optimization. Students can “hands-on” operate equipment such as laminar flow hoods, PCR instruments, and electrophoresis tanks in the virtual laboratory, gaining an experience close to real-world operations. Virtual experiments not only address the limitations of physical laboratory conditions but also allow students to boldly experiment and practice repeatedly in a safe environment, fostering their experimental design and problem-solving skills.

### 4.2 Intelligent Teaching Model

#### (1) AI-Assisted Personalized Learning Path Recommendations

Based on knowledge graphs and learning behavior data, an AI learning assistant is developed to generate personalized learning paths for each student. The system assesses students’ foundational knowledge through pre-tests, tracks their progress and performance in real time during the learning process, and dynamically adjusts subsequent learning content. For example, for students who have mastered “DNA Structure,” the system can skip basic review and proceed directly to advanced learning on “DNA Damage Repair” ; conversely, for students struggling with the “Enzyme Kinetics” section, the system pushes supplementary explanatory videos and targeted practice questions. This “tailored” learning support ensures that students with varying backgrounds and paces receive the most suitable learning resources, achieving true personalized instruction.

#### (2) Real-time Feedback System Based on Learning Behavior Data

Establish a Learning Analytics Dashboard to provide visual feedback on learning data for both teachers and students. On the teacher side, instructors can view the class’s overall learning progress, heatmaps of knowledge mastery, and distributions of common errors to promptly identify teaching weaknesses and adjust instructional strategies (Singh and Arya 2020). On the student side, the dashboard displays individual time allocation for learning, radar charts of knowledge mastery, and comparative analysis with the class, helping students understand their own learning status and make self-adjustments. The real-time feedback system should also include an early warning function. When a student experiences learning stagnation (such as not logging in for several consecutive days or a sudden drop in video completion rates) or accumulating difficulties (such as a persistently high error rate on exercises in a specific chapter), the system automatically sends alerts to both teachers and students, triggering intervention measures. This “data-driven instructional decision-making” shifts teaching from being “experience-driven” to “evidence-driven,” significantly enhancing the precision of instruction (Anwar, Muti’ah et al. 2024).

### 4.3 Innovation in Experimental Instruction

#### (1) Hybrid Virtual-Physical Experimentation Model

A three-stage experimental teaching model is adopted: “virtual rehearsal—physical operation—virtual extension”. Before class, students complete experimental preparation on a virtual platform to familiarize themselves with operational procedures and precautions; they are only permitted to enter the laboratory after

passing a virtual operation assessment (Vázquez-Salazar 2026). During class, students conduct actual experiments, allowing instructors to devote more time to personalized guidance and in-depth discussions; After class, students can conduct extension experiments on the virtual platform—such as altering experimental conditions to observe changes in results or designing and optimizing experimental protocols—to consolidate and deepen their experimental skills.

This model effectively addresses the issues of limited class time and insufficient equipment, improving the success rate of hands-on experiments and teaching efficiency. At the same time, the “repeatability” and “reversibility” of the virtual platform allow students to explore boldly, fostering a spirit of scientific inquiry. For example, in PCR experiments, students can test different parameters—such as annealing temperature, primer concentration, and cycle number—in a virtual environment to observe their impact on amplification results. This helps them develop a systematic understanding of experimental conditions, which they can then apply to hands-on experiments.

## (2) Introduction of Digital Bioinformatics Tools

Integrating bioinformatics tools into both theoretical and laboratory instruction enables students to master the ability to solve biochemical problems using computational methods. Specifically, this includes: sequence analysis tools for retrieving and aligning gene and protein sequences; structural analysis tools for visualizing and analyzing protein structures; molecular docking software for predicting intermolecular interactions; and pathway analysis tools for analyzing metabolic networks.

## 5. Conclusion

Driving the reform of teaching methods in biochemistry and molecular biology through digital and intelligent technologies is an inevitable choice for addressing the challenges of training biomedical engineering talent in the new era, as well as a crucial step toward modernizing pharmaceutical education. However, the engineering nature of the biomedical engineering discipline, its interdisciplinary characteristics, and the rapid evolution of technology dictate the unique nature of its reform path. During implementation, it is essential to place high priority on technological ethics and data privacy protection, while guarding against algorithmic bias and the risks of over-reliance on technology; Efforts must be focused on facilitating the transformation of the teacher’s role and promoting continuous professional development, ensuring that educators successfully transition from “authorities on knowledge” to “learning designers” and “growth mentors.”

Looking ahead, as Artificial Intelligence Generated Content (AIGC) technology matures, AI-assisted creation of teaching materials will become feasible, significantly enhancing the efficiency and personalization of educational resources; the development of Metaverse technology will provide entirely new scenarios for immersive virtual laboratories and cross-regional collaborative learning. The educational applications of these cutting-edge technologies warrant ongoing attention and active exploration. Ultimately, the goal of digital and intelligent education is not to showcase the technology itself, but to return to the essence of education—stimulating learning motivation, cultivating higher-order skills, and promoting well-rounded development—to nurture outstanding talent with innovative spirit and practical capabilities for the biopharmaceutical industry.

## References

- Amor, E. C., Attanayake, A. P., Nicolas, M. G., Yu, G. F. B. and Macaulay, J. O. (2020). "Undergraduate Education in Biochemistry and Molecular Biology: A Parallel Session at Theiubmb/Psbmb2019 "Harnessing Interdisciplinary Education in Biochemistry and Molecular Biology" Conference", *Biochemistry and Molecular Biology Education* **48**(6), 602-607.
- Anwar, Y. A. S., Muti'ah, M. and Dewi, Y. K. (2024). "An Integrated Laboratory Work to Improve Students' Practical Skills and Attitudes toward Biochemistry in the Biochemistry Course", *Biochemistry and Molecular Biology Education* **52**(1), 36-44.
- Chen, Y. L., Zhang, J. L. and Assoc Computing, M. (2024). "Research on the Teaching Path of Home Space Design Based on Stable Diffusion Intelligent Generation Technology in the Digital Economy Era", *International Conference on Computer and Multimedia Technology (ICCMT)*, Sanming, PEOPLES R CHINA.
- Chen, Y. Y., Lei, S. H., Yang, Q., Zhu, J. and Xiang, Y. F. (2025). "Deep Learning-Driven Transformation of Remote Sensing Education for Ecological Civilization and Sustainable Development", *Sustainability* **17**(17), 7958.

- Fan, G. H., Huang, Z. J., Sun, H., Li, Z. H., Wu, X. M., Li, C. S., Lin, C. B., Zhan, W. J., Li, Z. B., Zheng, C. W., Xie, W. J., Zou, H. Y., Wu, B. L., Fang, W. K., Xu, L. Y., Yang, M. H., Zheng, S. Y. and Li, E. M. (2023). "Construction and Analysis of Evaluation Model for Medical Students' Innovation Competency Based on Research-Oriented Biochemistry and Molecular Biology Course in China", *Biochemistry and Molecular Biology Education* **51**(3), 263-275.
- Gomez, N. A. (2020). "Using E-Notebooks to Explore Biochemistry with an Agricultural Lens", *Biochemistry and Molecular Biology Education* **48**(6), 667-669.
- Guo, H. X., Feng, H., Zeng, G. and Zeng, Q. C. (2025). "Evaluation of Digital Technology Integration into University Teaching Acceptance in the Context of Green and Sustainable Development", *Polish Journal of Environmental Studies* **34**(5), 5099-5110.
- Ji, H. Y., Zhu, K. L., Shen, Z. Y. and Zhu, H. X. (2023). "Research on the Application and Effect of Flipped-Classroom Combined with Tbl Teaching Model in Wechat-Platform-Based Biochemical Teaching under the Trend of Covid-19", *Bmc Medical Education* **23**(1), 679.
- Jiang, Y., Ma, H. J., Zhang, S. F., Bao, H. Y., Chen, C. and Luo, Y. (2025). "Mechanism for Credibility Assessment of Online Health Information by Medical Students in the Digital-Intelligent Age-a Grounded Theory Study in China", *Bmc Medical Education* **25**(1), 1692.
- Nimesh, A. (2025). "Potential of Role Play as an Educational Tool in Biochemistry to Facilitate Medical Education", *Biochemistry and Molecular Biology Education* **53**(2), 200-208.
- Silva, M. J. E., Cecilio, M. S. and Pazinato, M. S. (2026). "Biochemistry Learning in Higher Education: A Systematic Review on Methodologies and Teaching Resources", *Biochemistry and Molecular Biology Education* **54**(1), 29-48.
- Singh, S. and Arya, A. (2020). "A Hybrid Flipped-Classroom Approach for Online Teaching of Biochemistry in Developing Countries During Covid-19 Crisis", *Biochemistry and Molecular Biology Education* **48**(5), 502-503.
- Vázquez-Salazar, A. (2026). "An Idea to Explore: From How to Why: Using Evolutionary Biochemistry to Inspire Biochemistry Education", *Biochemistry and Molecular Biology Education*.
- Wang, R. S., Li, J. N., Shi, W. B. and Li, X. (2021). "Application of Artificial Intelligence Techniques in Operating Mode of Professors' Academic Governance in American Research Universities", *Wireless Communications & Mobile Computing* **2021**, 3415125.
- Wang, W., Tian, K. L., Zeng, J. P., Zhu, D. Y., Liu, Z. F., Zhang, P. J., Bi, W. X. and Ren, G. J. (2022). "Assessment of Blended Teaching Mode on Biochemistry", *Progress in Biochemistry and Biophysics* **49**(8), 1607-1614.
- Wang, X., Li, M. Q., Du, Y. L., Yang, H., Ran, J. S. and Zhang, H. Y. (2026). "Building a New Ecosystem for Digital-Intelligent Teaching of Veterinary Infectious Diseases in Southwest Chinese Universities: Theoretical Framework and Practical Pathways", *Frontiers in Veterinary Science* **13**, 1746110.
- Yang, R. W. (2020). "How to Arouse Students' Desire to Learn Biochemistry", *Biochemistry and Molecular Biology Education* **48**(6), 572-578.
- Zhang, C. H., Wen, M. G., Tong, K., Chen, Z. X., Wen, Q., Yang, T. T. and Liu, Q. J. (2022). "Institutional Adoption and Implementation of Blended Learning in the Era of Intelligent Education", *Applied Sciences-Basel* **12**(17), 8846.
- Zhang, Z. R. (2022). "Application of Digital Intelligent Communication Technology in Contemporary Comparative Education Methodology", *Alexandria Engineering Journal* **61**(6), 4647-4657.
- Zhong, Q. Y., Jiang, J. J., Bai, W. T., Yin, Z. H., Liao, Z. Y. and Zhong, X. H. (2025). "Application of Digital-Intelligent Technologies in Physical Education: A Systematic Review", *Frontiers in Public Health* **13**, 1626603.