

Practical Strategies and Application Exploration of Virtual Simulation Experiment Teaching for Biochemistry in Colleges and Universities

Ruihong Zhao, Mengdi Wang, Jing Li, Xinming Yin, Jinhuan He*

College of Life Sciences, Henan University of Animal Husbandry and Economy, Zhengzhou 450046, China

*Author to whom correspondence should be addressed.

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Abstract: This paper explores the concept of virtual simulation experiment teaching, and based on the current situation and existing problems of biochemical experimental teaching in colleges and universities, puts forward effective improvement strategies. The purpose is to exert the educational practical value, empower students' career development, and fundamentally enhance their comprehensive quality and core competitiveness. Empowering higher education with digital technologies and promoting the modernization and digital transformation of biochemical experimental education in universities, virtual simulation experiment teaching is worthy of in-depth exploration and practice.

Keywords: Colleges and universities; Biochemistry; Virtual simulation experimental teaching; Current situations

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1. Introduction

1.1. Concept of virtual simulation experiment teaching

Virtual simulation experiment teaching builds virtual network scenarios, enabling students to immerse themselves in a realistic experimental simulation environment to complete project exploration and practical training. With the continuous maturity of this technology, it can be applied to professional practice and scientific research innovation, and is more effective compared with traditional experiments. As we all know, biochemistry is a core discipline in the field of life sciences. Many aspects of its research and experiments cannot be intuitively presented to students, leading to experimental limitations, which are not conducive to cultivating students' innovative awareness and practical capabilities. The application of virtual simulation experiments precisely makes up for this deficiency, and effectively empowers biochemical experimental teaching with digital technologies, simulation platforms and abundant resources, inspiring students in various aspects. Therefore, the following discussion focuses on the practical strategies of virtual simulation experiment teaching for biochemistry in colleges and universities^[1].

1.2. Implementation conditions of virtual simulation experiment teaching

Virtual simulation experiment teaching relies on the support of computers, virtual reality, and other related technologies to build a highly simulated experimental environment and operation platform, which supports experimental research in multiple disciplinary fields as well as students' experimental design and independent research. It breaks through the traditional laboratory teaching mode, naturally saves experimental costs, and makes knowledge more vivid and concrete ^[2,3]. However, this requires universities to purchase advanced equipment, build a high-quality teaching team, and conduct scientific and standardized operation and maintenance, to create a high-quality virtual simulation experimental environment and effectively provide students with an immersive and interactive learning experience. In recent years, with the in-depth advancement of the digital transformation of education, virtual simulation experiment teaching has become an important direction for the reform of higher education and vocational education, and has been widely applied in many disciplines such as medicine, engineering, chemistry, physics, and biology, effectively supporting the construction of a high-quality talent training system.

1.3. Significance of virtual simulation experiment teaching for biochemistry in colleges and universities

The reform of biochemical experimental teaching in colleges and universities is of far-reaching significance, mainly reflected in the following three aspects: First, it makes up for the shortage of traditional teaching resources. The introduction of virtual simulation resources for biochemical experiments complements traditional textbooks and experimental guidelines. In particular, some universities have limited funds and material resources, making it difficult to purchase high-cost equipment and specimens in a short time. In addition, some biochemical reagents are classified as dangerous goods, and their use in physical experiments cannot meet the strict requirements of experimental safety management ^[4]. Obviously, virtual simulation resources make up for this deficiency. Through video presentation and software design, they can meet the needs of experimental practice on a large scale. Specifically, through modeling, interactive operation, intelligent feedback, and other means, students can conduct repeated experimental practice in a safe and low-cost virtual environment.

Second, it strengthens students' dynamic understanding of biochemical knowledge, and effectively hones their higher-order thinking, innovative awareness and practical abilities. Furthermore, virtual simulation experiments are virtual in operation form but practical in educational attributes. After several experiments, students' digital literacy and intellectual literacy are developed, laying a solid foundation for their long-term career development in the future. Through virtual simulation experiments, students can intuitively observe the internal physiological and biochemical changes of cells and summarize the underlying core principles, thus deepening their understanding of key theoretical knowledge. Students can also apply digital technologies to independently design and build their own virtual experimental scenarios, achieving multiple educational effects at once.

Third, it promotes the innovation of experimental modes and accelerates the realization of educational equity. Supported by personalized learning paths and process-based teaching evaluation, it has effectively changed the traditional teaching mode. Teachers can accurately diagnose students' learning difficulties according to their operation tracks and implement differentiated guidance. Universities in less developed regions can also access high-quality experimental teaching resources through virtual simulation platforms, thus gradually promoting the modernization of their biochemical experimental teaching.

2. Current situation and problems of biochemistry experiment teaching in colleges and universities

2.1. Insufficient class hours and outdated content

In the practical teaching section of biochemistry in colleges and universities, there is an obvious shortage of experimental class hours, and the teaching content is outdated, which fails to effectively cultivate students' practical operating abilities. Many schools still focus on traditional verification experiments, and even if group experiments are arranged, students are only required to verify the known principles in textbooks. Even when some students conduct physical experiments, they will falsify their own experimental phenomena and results to match the conclusions in textbooks if their experiments fail to achieve the expected results, which runs counter to the original purpose of the experiments^[5,6]. Some universities also neglect practical teaching, which is reflected in aging experimental equipment, insufficient experimental teaching resources, and teachers' inadequate attention to experimental teaching. This is obviously not conducive to cultivating students' practical operation ability, problem-solving ability and engineering practice ability, and further restricts the development of their scientific research literacy and professional literacy.

2.2. Stagnant digital transformation

The digital construction of biochemistry courses is also inadequate, mainly reflected in outdated digital teaching resources and the lack of digital literacy among both teachers and students. The backward construction of digital teaching resources directly leads to great difficulties in the implementation of virtual simulation experiments and other online experimental teaching forms, thus failing to meet the diverse learning needs of students at different levels. The lack of digital literacy among teachers and students also makes it impossible for them to use modern technologies or tools to solve problems, which limits the dual improvement of their professional quality and digital literacy^[7]. Furthermore, although electronic experimental reports have been gradually promoted, there are still problems such as poor platform compatibility, delayed marking, slow feedback, and non-standard data storage, which seriously affect the use experience of teachers and students. All the above problems lead to the digital reform staying on the surface and failing to truly empower the substantive improvement of experimental teaching quality.

3. Practical strategies of virtual simulation experiment teaching for biochemistry in colleges and universities

3.1. Promote virtual experiment teaching by module division

The primary task of the reform of biochemical experimental teaching in colleges and universities is to construct a scientific and systematic modular curriculum system, namely, to design modular teaching tasks to drive students' independent thinking, autonomous inquiry, and cooperative learning. In teaching practice, with ability cultivation as the guide and technological innovation as the driver, we adopt a combination of virtual and real teaching methods to help students deepen their understanding of experimental principles and logical relationships step by step. Specifically, it can be subdivided into four levels: basic skill training module, core principle verification module, comprehensive technology integration module, and scientific research innovation exploration module. The basic skill training module focuses on routine experimental operations such as pipetting, centrifugation, electrophoresis, and spectrophotometry operations. Through high-fidelity 3D modeling and interactive operation interfaces, students can practice repeatedly in a risk-free environment to form muscle memory and standard

awareness. The core principle verification module focuses on key biochemical processes such as enzyme kinetics, protein denaturation and renaturation, and DNA replication and transcription. It uses dynamic visualization technology to materialize abstract molecular mechanisms, helping students build a cognitive bridge between micro and macro levels. The comprehensive technology integration module emphasizes the combination of multiple technologies, such as connecting SDS-PAGE, Western Blot, and mass spectrometry analysis to simulate real scientific research processes and cultivate students' systematic thinking and experimental design abilities [8,9]. The scientific research innovation exploration module opens the authority of parameter setting and variable control, allowing students to design their own experimental schemes, such as exploring the effect of different pH values on enzyme activity or simulating the intervention effect of drugs on metabolic pathways. Each module can operate independently and can also realize intelligent association through knowledge graphs, which allows teachers to flexibly combine these modules according to the teaching progress and facilitates personalized learning for students.

3.2. Strengthen the interactive experience and improve the intelligent feedback mechanism

To truly exert the advantages of virtual simulation in biochemical experimental teaching, it is necessary to deeply strengthen the immersive interactive experience and improve the intelligent feedback mechanism. By virtue of VR/AR, WebGL and real-time physical engine technologies, we construct a highly simulated virtual laboratory environment. In this environment, students can move freely, grasp experimental instruments, prepare reagents, operate equipment and observe the dynamic changes of experimental reaction processes in real time. The most intuitive examples include the migration of fluorescently labeled proteins in gels and the change curve of enzyme-catalyzed reaction rate with substrate concentration. This “learning by doing” mode effectively arouses students' learning motivation and improves the efficiency of knowledge internalization [10]. In some cases, students first simulate on the virtual simulation experiment platform and then conduct real experimental practice based on experience, which can bring them great benefits. We believe that it is also necessary to apply an intelligent management system in biochemical virtual simulation experiment teaching, to effectively transform virtual teaching resources into practical educational advantages. In the specific system design, an evaluation model based on rule engines and machine learning algorithms is embedded to monitor each step of students' experimental operations in real time with millisecond precision: if students fail to wear protective gloves, make wrong sample addition order, or set inappropriate centrifugation parameters, the system immediately pops up a warning and provides correct operation guidance. After the experiment, a multi-dimensional evaluation report is automatically generated, covering indicators such as operation standardization, data accuracy, time efficiency, and error type distribution. This prompts students to actively interact with the intelligent system, fully apply its functions, and realize effective interactive communication and timely feedback, thus helping them consolidate experimental skills, foster a rigorous scientific attitude, and develop critical thinking ability, and lay a solid foundation for students to engage in scientific research-related work in the future.

3.3. Promote interdisciplinary integration and research-oriented teaching

We further deepen the reform of biochemistry courses and use virtual simulation experiment platforms to guide students to conduct practical applications of interdisciplinary knowledge. This teaching mode breaks through the boundaries of traditional disciplines, enabling students to comprehensively master the knowledge of molecular biology, bioinformatics, structural biology, systems biology, and even artificial intelligence, and carry out in-depth research-oriented learning and exploration. For example, in the “Protein Purification and Identification”

experiment, size exclusion chromatography, His-tag affinity chromatography, circular dichroism (CD) analysis, and AlphaFold2 structure prediction tools are integrated, guiding students to establish a systematic and integrated cognitive system of proteins from expression and purification to structural analysis and functional research^[11,12]. In the “Metabolic Regulation” experiment, combined with KEGG or MetaCyc databases, a dynamic metabolic network model is constructed, allowing students to simulate the flux reprogramming of glycolysis, TCA cycle and other pathways under diabetic or cancer conditions, and observe the system response by virtual knockout of key enzyme genes. Obviously, such experimental research is more practical and in line with real scientific research scenarios. Even if students have deficiencies in operational details, they can gradually internalize professional knowledge through video demonstrations and virtual case analysis, and effectively accumulate research experience on cutting-edge issues in biochemistry through virtual simulation experiments. Therefore, in the design of corresponding platform resources, real scientific research data sets can be introduced in the future, allowing students to complete data analysis, chart drawing and conclusion derivation on the virtual platform, cultivating their data literacy and scientific research thinking^[13]. Virtual simulation experiments integrate interdisciplinary knowledge, drive students to carry out interdisciplinary experimental research, and build a solid bridge between biochemical theoretical teaching and scientific research practice, truly realizing the coordination of teaching, scientific research and education, and laying a solid foundation for the innovative development of higher education.

3.4. Optimize the evaluation of virtual simulation experiment teaching

The sustainable development of virtual simulation experiment teaching is inseparable from a scientific, dynamic, and multi-dimensional quality evaluation system and a sound continuous optimization mechanism. First of all, an evaluation system covering the entire chain of “input-process-output” should be constructed. At the input stage, we evaluate the scientificity of experimental content, the advancement of applied technologies and the consistency with teaching objectives; at the process stage, we quantify students’ learning participation and cognitive load through the analysis of learning behavior data; at the output stage, we comprehensively evaluate learning effects by combining knowledge tests, skill assessments, experimental report reviews and peer evaluations. Secondly, the evaluation methods should be diversified, including automatic system scoring, teacher’s manual evaluation, student self-evaluation and peer review, to ensure the objectivity and comprehensiveness of the evaluation results. More importantly, we should establish a closed-loop optimization mechanism of “data-driven feedback and iteration”. The platform should regularly collect user logs, questionnaire feedback and teaching effect data, identify common problems in teaching by using educational data mining technologies, and then optimize the system interaction logic, supplement targeted guidance prompts or reconstruct the experimental teaching process accordingly^[14]. At the same time, set up a teachers’ cooperation community, encourage front-line teachers to share teaching cases and put forward improvement suggestions, and form a co-construction and sharing ecology.

In addition, universities should formulate clear standards for credit recognition and score conversion between virtual experiments and offline physical experiments to ensure the formal status of virtual simulation experiment teaching in the talent training system^[15]. Through this mechanism, virtual simulation experiment teaching can not only maintain the advancement of content and the effectiveness of teaching, but also continuously evolve in practice, truly becoming the core support for the high-quality development of biochemical education in colleges and universities.

4. Conclusion

In summary, the reform of biochemical experimental teaching in colleges and universities is not an overnight task. By applying virtual simulation experiment technologies to construct high-quality platform resources and using virtual scenarios to assist students in thinking, research, innovation and practical training, we can achieve a multiplier effect in biochemical experimental teaching practice. Students should also actively participate in this teaching reform and practice, use new technologies and platforms to strengthen their mastery of professional knowledge, improve learning efficiency, and effectively exercise their biochemical experimental operation abilities, laying a solid foundation for their long-term career development in the future.

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Disclosure statement

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