Practical and Innovative Research on the Three-Dimensional Integration of "Clinical Thinking-Operational Ability-Post Connection" in Virtual Simulation for Higher Vocational Medical Laboratory Technology

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Abstract: Objective: Aiming at the disconnection between talents majoring in higher vocational medical laboratory technology and industrial demands in clinical thinking, intelligent operation and post collaboration ability under the background of Free Trade Port construction, this paper explores a new talent training mode of "three-dimensional integration" based on virtual simulation technology. Methods: With the industry-education integration mechanism, the core competencies of medical posts in the Free Trade Port were analyzed, a three-in-one teaching system of "theory-virtual simulation-clinical practice" was constructed, a virtual simulation resource database featuring tropical disease detection and cross-border specimen processing was developed, and a multi-dimensional evaluation system was established. Results: This mode successfully remedied students' deficiencies in cross-border inspection report interpretation, AI equipment operation and data sharing, and realized the transformation from single skill training to comprehensive professional ability cultivation. Conclusion: The three-dimensional integration mode of "clinical thinking-operational ability-post connection" is an effective way to improve the ability of serving regional economy and post competence of higher vocational medical laboratory talents.

***Keywords*:** virtual simulation; medical laboratory technology; industry-education integration; clinical thinking; post connection

1. Introduction

With the implementation of the Overall Plan for the Construction of Hainan Free Trade Port and the advancement of the "Healthy China" strategy, cross-border medical treatment and related industries have witnessed explosive growth, raising new requirements for medical laboratory technology talents, such as mastering diverse capabilities [1]. Currently, higher vocational medical laboratory education is confronted with "three dilemmas": the cultivation of clinical thinking lags behind, leaving students deficient in the ability to judge complex clinical situations; operational methods are disconnected from industrial development, causing students "skill anxiety"; and post connection is rigid, with gaps between school teaching and real medical scenarios in the Free Trade Port [2]. Therefore, integrating post demands with Free Trade Port characteristics into teaching by means of modern information technology, especially virtual simulation technology, has become an urgent issue to be addressed. This paper aims to construct a three-dimensional integration system and explore a new path for cultivating medical laboratory talents through deep integration of industry and education.

2. Analysis of Post Demands and Competency Dimensions under the Background of Free Trade Port

2.1 Investigation of Post Demands and Analysis of Pain Points

Our research team conducted a six-month field investigation in multiple tertiary hospitals, independent clinical laboratories (ICL), and cross-border medical service platforms in the Free Trade Port, and found significant changes in the industry's demand for vocational talents:

In terms of clinical thinking, enterprises urgently need talents with the ability of integrated analysis of "disease-syndrome-testing". In tropical disease-prevalent areas, students are required to have morphological identification and tracing capabilities for special pathogens. However, most current students only stay at morphological description and lack clinical correlation thinking.

In terms of operational ability, with the automation and intelligent development of laboratory medicine, enterprises have high requirements for proficiency in operating AI-assisted diagnosis systems and fully automatic biochemical immune assembly lines, while the update of practical training equipment in colleges lags behind.

In terms of post connection, students need to master standardized operating procedures (SOP) and data security sharing

norms in cross-institutional medical collaboration, but they currently lack such collaborative process training in school [3].

2.2 Construction of "Three-Dimensional Competency" Model

Based on the investigation, a three-dimensional competency model of clinical thinking–operational ability–post connection was established. The first dimension, clinical thinking, emphasizes the clinical interpretation of test results and abnormal value management. The second dimension, operational ability, focuses on the standardized operation and troubleshooting of precision instruments. The third dimension, post connection, stresses professional literacy, communication and collaboration, and the implementation of standardized procedures.

By sorting out the core post responsibilities, we formulated the Medical Laboratory Post Competency Requirements List for the Free Trade Port covering 28 core indicators, providing an accurate target for the subsequent construction of the resource database.

3. Construction of Teaching System for Three-Dimensional Integration Supported by Virtual Simulation

3.1 Three-in-One Architecture of "Theory-Virtual Simulation-Clinical Practice"

To solve the problem of "disconnection between learning and application", we reconstructed the curriculum system and established the principle of "combination of virtuality and reality, supplementing reality with virtuality". Relying on four core courses including Basic Clinical Laboratory Examination, Microbiological Laboratory Technology, Immunological Laboratory Technology and Clinical Hematological Laboratory Technology, virtual simulation is used as a "bridge" connecting theory and clinical practice [4].

3.2 Three-Level Progressive Training Module of "Basic-Comprehensive-Post"

Three training levels are designed via the virtual simulation platform to promote the spiral improvement of students' abilities. The basic operation module uses 3D modeling to build a virtual operating environment for core instruments, allowing students to practice disassembly repeatedly to improve operational accuracy and standardization, and solve the problem of fearing to use real equipment. The comprehensive case module introduces real clinical cases to construct "virtual patients"; students independently select test items, analyze results and recheck abnormal data, integrating operation and clinical thinking to change the situation of acting without thinking. The post simulation module simulates characteristic scenarios of the Free Trade Port, where students experience the whole process of specimen management, focusing on training relevant protocols and cross-cultural communication skills to achieve seamless connection with employment positions.

4. Construction and Application of Characteristic Resource Database from the Perspective of Industry-Education Integration

4.1 Co-Construction of Characteristic Case Resource Database by School and Enterprise

Industry-education integration is the key to resource database construction. We have established a "dual-subject" development mechanism of school-enterprise cooperation, and invited directors of hospital clinical laboratories, senior technicians and school teachers to form a development team.

Core contents of the resource database (with document characteristics):

Tropical disease pathogen atlas database: Collect high-definition microscopic images and 3D models of common tropical pathogens in the Free Trade Port, making up for the shortage of rare case specimens in traditional teaching.

Cross-border specimen processing virtual simulation system: Simulate the special packaging, cold chain transportation and biosafety declaration procedures of cross-border medical specimens, which is a unique teaching resource of the Free Trade Port.

Intelligent instrument operation database: Develop virtual operation programs for the current mainstream fully automatic assembly lines (TLA) in hospitals, enabling students to be familiar with cutting-edge industrial equipment in advance [5].

4.2 Technical Implementation and Feedback Mechanism of the Resource Database

In the process of resource database construction, an Intelligent Feedback System is embedded. When students have illegal operations (such as operating without gloves, incorrect sample addition volume) or thinking deviations (such as missing key indicators) in virtual operations, the system will immediately pop up a warning box and provide standard operation videos and error correction guidance. This "learning by doing, correcting by mistakes" mechanism has significantly enhanced the practicality of teaching.

5. Evaluation System of Three-Dimensional Integration and Long-Term Collaboration Mechanism

5.1 Multi-Dimensional and Three-Dimensional Evaluation System

Abandoning the single summative assessment method, an evaluation system combining "process evaluation + summative evaluation + post evaluation" is constructed:

Process evaluation (40%): With the help of the big data recording function of the virtual simulation platform, analyze the standardization of students' operation, the logic of thinking path and error correction ability.

Summative evaluation (30%): Assess students' ability to solve complex problems through comprehensive virtual case assessment.

Post evaluation (30%): During the internship period, enterprise tutors score according to students' performance in real posts (such as the implementation degree of specimen processing standards, teamwork ability, etc.).

5.2 Collaborative Mechanism of "Co-Construction, Co-Implementation, Co-Evaluation and Sharing"

To ensure the continuous update of the resource database and the long-term effectiveness of teaching quality, a close school-enterprise cooperation mechanism is built:

Co-construction: Enterprises provide real cases and technical standards, and schools are responsible for teaching transformation and platform construction.

Co-implementation: The "dual-tutor system" is implemented, and enterprise experts participate in the guidance of virtual simulation training remotely or on site.

Co-evaluation: Schools and enterprises jointly formulate assessment standards, and enterprises deeply participate in the teaching evaluation link.

Sharing: A regional medical laboratory virtual simulation resource center is established, which not only serves on-campus students, but also is open to enterprise employees for pre-job training and skill improvement, realizing the socialized sharing of educational resources.

6. Conclusion

The three-dimensional integration mode of "clinical thinking-operational ability-post connection" in virtual simulation for higher vocational medical laboratory technology is an inevitable choice to adapt to the construction of Free Trade Port and the reform of digital education. The introduction of virtual simulation technology not only solves the problems of "high risk, high cost and difficult reproduction" in medical laboratory teaching, but more importantly, introduces the latest industry standards, cases and technologies into the classroom through industry-education integration. This mode transforms students from passive skill imitators to active clinical decision-making participants, effectively improves the post competence and employment competitiveness of graduates, and provides solid talent support for the development of regional medical and health undertakings.

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