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Role Transformation and Development Paths of University Medical Functional Experiment Technicians in the AI Era

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Abstract

The in-depth penetration of artificial intelligence (AI) technology is driving a systematic transformation of the medical education system in universities. This represents the core trend in the digital development of current medical education and has been widely confirmed by relevant studies both domestically and internationally. As a key link connecting basic medicine and clinical practice, the role reconstruction and upgrading of medical function laboratory technicians—the core practitioners of medical function experiments—have become a research hotspot in the digitalization of medical education in recent years. As a review article, this paper systematically sorts out the application practices of AI in medical function experiments in existing research, comprehensively analyzes the role positioning and generally recognized inherent limitations of traditional function laboratory technicians, integrates current research findings, and expounds on the transformation requirements for laboratory technicians in four dimensions: technical competence, teaching support, scientific research assistance, and management functions in the AI era. It further summarizes and refines a four-dimensional development path of "in-depth technical exploration-teaching innovation-scientific research empowerment-management upgrading", which is corroborated with existing application cases. Studies show that only by completing the core transformation from "traditional operational performers" to "builders of intelligent experimental ecosystems" can university medical function laboratory technicians accurately adapt to the era of digital reform in medical education, provide high-quality support for medical talent training, and conform to the inevitable trend of the current reform of medical function experiment teaching.

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Keywords

AI Era, Medical Functional Experiment Technicians, Role Transformation, Development Path

1. Introduction

Medical functional experiment technicians refer to professionals engaged in experimental technical operations, teaching assistance, equipment operation and maintenance, resource management, and other tasks in medical functional experiment laboratories in universities, providing technical support for medical functional experiment teaching and scientific research. The intelligent experiment ecosystem is a comprehensive experimental operation system that integrates the entire process of experimental teaching, scientific research, and management, with AI, virtual simulation, and other digital technologies as its core, achieving intelligent experimental equipment, personalized teaching guidance, precise scientific research analysis, and efficient resource management. The dimension of technical capability transformation refers to the process of experimental technicians' transformation from mastering traditional experimental equipment operation skills to mastering intelligent experimental systems, conducting experimental data analysis, and integrating cross-disciplinary knowledge between medicine and AI. The dimension of teaching support transformation refers to the process of experimental technicians' transformation from providing standardized experimental operation guidance to relying on AI technology to design personalized virtual experiments, conduct precise teaching tutoring, and build a bridge between experiments and clinical practice. The dimension of scientific research assistance transformation refers to the process of experimental technicians' transformation from solely undertaking preliminary preparations for scientific research experiments to relying on AI technology to optimize experimental schemes, manage scientific research data, and participate in interdisciplinary scientific research collaboration, demonstrating deep scientific research support capabilities. The dimension of management function transformation refers to the process of experimental technicians' transformation from traditional experimental resource guarantee and basic management to relying on AI technology to achieve intelligent resource scheduling, data security protection, and performance quantitative evaluation, demonstrating the ability to build an intelligent experiment ecosystem.

Medical functional experiments integrate core knowledge from multiple disciplines such as physiology, pathophysiology, and pharmacology. They serve as a crucial medium for medical students to build a thought process of "theoretical learning-experimental practice-clinical application". This core value has gained widespread consensus in the field of medical education, and related studies have explicitly affirmed its importance in medical talent cultivation. Traditional medical functional experiments are centered around animal models and rely entirely on manual operations by experimenters, manual equipment adjustments, and subjective interpretation of experimental results. Their operational processes are characterized by strong practicality and high proceduralization, which is also a consensus summary of the traditional operational mode of medical functional experiments in academia [1]. Numerous studies have systematically reviewed and summarized the traditional operational process using the classic frog heart perfusion experiment as a typical case: experimenters manually capture frogs in advance and prepare the frog body (destroying the brain and spinal cord → cutting off the upper part of the torso and limbs → exposing the heart → ligating the aortic trunk) → manually constructing the perfusion device (connecting the frog heart cannula to the constant pressure perfusion bottle → adjusting the flow rate of the perfusion fluid) → completing the cardiac cannulation (inserting the cannula into the ventricle and ligating it) → connecting the physiological signal acquisition device → manually adjusting the composition of the perfusion fluid (such as adding different concentrations of K^+ and Ca^{2+} solutions) → visually observing the contraction and relaxation state of the frog heart and manually recording heart rate and heartbeat amplitude data. Related studies generally point out that this operational process has many drawbacks, including high resource consumption, certain safety risks, and the evaluation and analysis of experimental data being susceptible to subjective factors, making it difficult to ensure the objectivity and consistency of results [2]. This is also a widely recognized prominent issue in traditional medical functional experiment teaching, and many scholars have elaborated on it in their research.

With the gradual implementation of digital technologies such as AI and virtual simulation [3] in the field of medical education, scholars both domestically and internationally have conducted extensive practical explorations on the integration of digital technology and medical functional experiments, resulting in a series of valuable research outcomes and practical examples. Among them, numerous domestic universities, such as Nanjing Medical University, have taken the lead in constructing a three-in-one experimental teaching system that combines “virtual simulation + animal experiments + clinical relevance” [4], becoming a typical representative in the industry for the integration of digital technology and functional experiments. According to the practical research data statistics published by Nanjing Medical University in 2020, over 7,000 students have completed functional experiment learning through the functional digital human system under this system. The relevant research has provided detailed records and analysis of the application effect of this practical model. The existing research takes the virtual frog heart perfusion experiment as a specific case, systematically outlining its intelligent operation process: students select an experimental model in the system → AI guides the preparation of the virtual frog heart and the construction of the perfusion device, correcting non-standard operations in real-time → the system automatically configures the perfusion fluid and simulates concentration gradient changes → the virtual physiological signal collector transmits frog heart function data in real-time → AI automatically analyzes the data in the background and generates visual curves. Relevant practical research has fully confirmed that this system can highly simulate real physiological environments, while providing real-time feedback on operational data and intelligently offering operational guidance, strongly demonstrating the feasibility and effectiveness of digital technology in innovating medical functional experiment teaching [5]. This conclusion has been recognized by most relevant research.

Existing research generally believes that the integration of AI technology has not only changed the presentation form and operational process of functional experiments but also fundamentally reshaped the value chain of experimental teaching. Its impact spans the entire process of experimental design, implementation, and analysis, and relevant scholars have conducted comprehensive and in-depth discussions on this topic. In the experimental design stage, AI can analyze early-stage data through deep learning to optimize experimental schemes. Existing research, taking the experiment on the impact of drugs on heart rate as an example, has confirmed that AI can accurately predict the heart rate changes under different drug concentrations, providing scientific reference for experimental parameter design [6]. In the experimental implementation stage, AI can monitor the operating status of experimental equipment in real time. Related research has shown that when physiological signal collectors and other equipment malfunction, the system can automatically issue an alarm and indicate the cause of the failure [7]. In the experimental analysis stage, AI can achieve automated and intelligent analysis of experimental data, while virtual simulation technology can simulate high-risk and high-cost experimental scenarios, such as those involving toxic substances or high infection risks, effectively reducing experimental safety hazards and resource consumption [8]. This advantage has been recognized and supported by numerous related studies. Against this backdrop, existing research widely points out that the role of functional experimenters is no longer limited to the traditional "equipment administrator" and "operation demonstrator", but urgently needs to evolve towards a multifunctional role that is technically versatile, teaching innovative, research supportive, and management intelligent. This is also the core direction of current research on role transformation in the field of medical functional experiments, and related studies have all explored further in this transformational direction.

2. Role Orientation and Limitations of Traditional Functional Experiment Technicians

2.1. Core Functions of the Traditional Role

Under the traditional teaching model, the work of functional experiment technicians centers on experimental teaching support. They mainly undertake three basic functions: technical execution, resource management, and result verification, acting as fundamental supporters for the smooth implementation of experimental teaching. Their work runs through the entire process of various experimental operations.

(1) Technical execution: Responsible for the pre-experiment preparation of laboratory animals, the debugging and routine maintenance of experimental equipment such as physiological signal acquisition instruments, and on-site guidance for students to complete standardized operating procedures of basic experiments including isolated frog heart perfusion and rabbit arterial blood pressure measurement. Taking the rabbit arterial blood pressure measurement experiment as an example, technicians are required to complete the entire set of pre-experiment procedures: purchase healthy rabbits in advance and fast them for 12 hours → administer urethane anesthesia via the marginal ear vein after weighing → fix the rabbits supine on the operating table → shave the neck fur and make a skin incision → isolate the common carotid artery and vagus nerve → pass double sutures to ligate the distal end of the common carotid artery → clamp the proximal end and make an arteriotomy → insert and ligate the arterial cannula → connect the cannula to the physiological signal acquisition instrument → release the arterial clamp and record the baseline blood pressure. Subsequently, during the experiment, technicians guide students to perform operations such as cannulation, electrical stimulation of the vagus nerve, and intravenous injection of epinephrine, and correct non-standard operations in real time.

(2) Resource management: To coordinate inventory management and supply of laboratory consumables, maintain daily safe operation of the laboratory, and strictly handle ethical issues related to animal experiments, so as to provide resource support for the smooth progress of experimental procedures. Specifically, it includes regularly counting the quantity of consumables such as reagents (e.g., perfusion fluid, anesthetics, various ion solutions) and surgical instruments (e.g., frog heart cannulas, arterial cannulas, surgical scissors, hemostatic forceps) to ensure adequate supply; inspecting the operation of safety facilities such as fire protection and ventilation in the laboratory to eliminate potential safety hazards in a timely manner; and conducting feeding, anesthesia, sacrifice and other operations of laboratory animals in accordance with animal ethics guidelines to safeguard laboratory animal welfare.

(3) Result verification: Verify the standardization of students' experimental operations and the validity of experimental data through visual observation, manual recording and other methods, judge the authenticity and accuracy of data, and assist teachers in evaluating students' experimental scores. For example, after students complete the frog heart perfusion experiment, technicians need to check whether students have followed the standard procedure of "frog preparation-device setup-cannulation operation-perfusion fluid adjustment-data recording", observe whether the recorded heart rate and contractile amplitude data are consistent with the actual operation, and conduct a comprehensive evaluation of students' experimental results based on operational standardization.

2.2. Role Limitations in the AI Era

With the deep integration of AI technology into medical functional experiments, the traditional role of laboratory technicians has become increasingly incompatible with the digital and intelligent requirements of experimental teaching and scientific research. Their limitations are mainly manifested in three dimensions: technical capabilities, teaching support, and research assistance, and are particularly evident in the newly established experimental operation procedures.

(1) Single technical ability and insufficient digital literacy: The core competence of traditional laboratory technicians focuses on the implementation of conventional experimental procedures and equipment maintenance. They lack digital skills such as the use of AI tools and experimental data analysis, and are unable to independently operate new experimental equipment such as virtual simulation systems and intelligent evaluation platforms [9]. According to a 2025 survey conducted among senior functional laboratory technicians in Chinese medical colleges and universities, a significant majority (81.2%) reported having not received systematic training in artificial intelligence technologies.

(2) Superficial teaching support and lack of personalized guidance ability: Traditional laboratory technicians can only provide students with standardized guidance on experimental operation procedures. They are unable to use AI technology to analyze students' learning characteristics and weaknesses, generate personalized experimental schemes, or meet students' differentiated learning needs [10]. For instance, in the experiment of nerve-muscular junction transmission, different students encounter distinct problems during the preparation of the frog sciatic nerve-gastrocnemius muscle specimen. Some students are prone to nerve injury, while others fail to fix the specimen properly. However, traditional laboratory technicians can only provide guidance based on a unified teaching standard, without offering targeted procedural coaching for different students or designing advanced experimental content for those with greater learning capacity.

(3) Weak research support and lack of in-depth participation ability: Traditional laboratory technicians are confined to the preliminary preparation of scientific research experiments, such as preparing laboratory animals, equipment, and consumables, and completing pre-experimental operations according to fixed procedures. They are unable to use AI technology for in-depth research support such as experimental design optimization, experimental data mining, and data analysis [11]. This not only results in their low level of research participation but also restricts the cultivation of scientific research and innovation abilities among medical students to a certain extent. For example, in pharmacology-related functional experiments, traditional laboratory technicians cannot optimize the experimental process of "drug concentration gradient setting-administration method-data acquisition frequency" via AI technology, nor can they conduct in-depth mining of massive experimental data to extract valuable research conclusions, thus affecting the efficiency and innovation of scientific research.

3. Core Transformation Requirements for Functional Laboratory Technicians in the AI Era

Medical functional experiment teaching and scientific research in the AI era have put forward brand-new requirements for the competence and functions of laboratory technicians. Technicians are required to achieve an all-round transformation in four dimensions: technical capability, teaching support, scientific research assistance, and management functions. They should evolve from traditional experiment guarantors to core builders of the intelligent experiment ecosystem, with their work focus shifting from "executing experimental operation procedures" to "designing, optimizing, and empowering intelligent experimental operation procedures" [12].

3.1. Technical Competence: From "Equipment Operation" to "Intelligent System Mastery"

Laboratory technicians must break through traditional technical boundaries and establish a composite competence system integrating "traditional experimental skills + AI digital technologies". They should focus on mastering three core skills: intelligent equipment operation and maintenance, data analysis, and interdisciplinary integration, so as to achieve proficient mastery and efficient application of intelligent experimental systems and fully oversee the hybrid experimental procedures combining virtual and physical operations [13].

(1) Intelligent equipment operation and maintenance capability: Technicians should master the debugging, operation, and troubleshooting of intelligent devices such as virtual simulation experiment platforms and intelligent physiological signal analysis systems, and be capable of optimizing intelligent experimental procedures [8]. For example, functional laboratory technicians at Nanjing Medical University are required to skillfully operate the digital human system, adjust system parameters according to teaching needs, optimize the intelligent operation of experiments including virtual frog heart perfusion and rabbit arterial blood pressure measurement, and calibrate simulated physiological indicators through AI algorithms to ensure the authenticity and accuracy of virtual experiments [4]. When faults occur such as system lag or abnormal data transmission, they can quickly identify and resolve problems to ensure the smooth progress of experimental teaching.

(2) Data analysis capability: Technicians should be proficient in using AI analysis tools to process massive experimental data, identify patterns and anomalies from complex datasets, and provide scientific interpretation of results based on medical knowledge, so as to achieve deep integration between experimental procedures and data interpretation [11]. For example, in the measurement of myocardial contraction curves, technicians can use machine learning models to analyze myocardial contraction data collected from in vitro experiments, automatically mark abnormal fluctuation points, and correlate them with corresponding pathophysiological mechanisms. Meanwhile, by comparing with simulated data generated by AI in virtual experiments, they can analyze how different operational procedures affect experimental outcomes, providing data support for teaching and scientific research [7].

(3) Cross-disciplinary Integration Capability: Achieve the in-depth integration of medical expertise such as physiology and pathophysiology with AI technology. Be capable of using AI to visualize abstract medical knowledge and design knowledge explanation systems combined with experimental operating procedures. For example, knowledge graph technology can be used to construct an association model of "drug mechanism of action-physiological response changes-experimental operating procedures". Taking the frog heart perfusion experiment as an instance, the drug effect of "adding digitalis solution-enhanced myocardial contractility" is correlated with the operating procedures including "perfusate preparation, timing of drug administration, and data collection", so as to intuitively demonstrate the internal relationship among drugs, operations and physiological indicators, and assist students in understanding experimental principles and medical knowledge.

3.2. Teaching Support: From "Standardized Guidance" to "Personalized Empowerment"

AI technology provides technical support for precise and personalized teaching. Laboratory instructors should transform their teaching support methods based on AI technology and undertake three new roles: virtual experiment designer, intelligent teaching assistant, and bridge-builder connecting clinical practice. This enables an upgrade from "standardized guidance" to "personalized empowerment" and helps design tailored experimental procedures for students with diverse needs [10].

(1) Virtual Experiment Designer: Participate in the development and design of personalized virtual experiment scenarios, and formulate differentiated virtual experiment procedures according to students' knowledge foundations and learning needs [14]. For instance, for students with weak foundations, a step-by-step guided virtual frog heart perfusion experiment can be designed, which breaks the procedure into five core stages: frog preparation, device setup, cannulation, perfusate adjustment, and data recording. Each step is equipped with AI intelligent prompts; the system provides real-time error correction when students make mistakes and synchronously pushes knowledge explanations for the corresponding step, helping students gradually master experimental skills. For students with solid foundations, an independent-design experiment mode can be adopted, allowing them to freely set perfusate components, concentration gradients, and action durations, so as to cultivate their experimental design ability.

(2) Intelligent Teaching Assistant: With the support of an AI intelligent evaluation system, it tracks students' experimental operation data throughout the entire process, including operation duration, procedural standardization, operation success rate, and accuracy of data recording. Through data analysis, it identifies students' weak learning modules, such as "rabbit arterial cannulation" and "nerve-muscle preparation", and pushes targeted virtual training procedures to students, so as to achieve precise tutoring and personalized improvement. For example, for students who are unskilled in arterial cannulation, it pushes a special virtual train-

ing procedure of "cannulation angle adjustment-ligation strength control-pipeline connection" to repeatedly strengthen the weak links.

(3) Builder of Clinical Relevance Bridges: AI technology is used to build a connection channel between experimental teaching and clinical practice, breaking the teaching dilemma of "disconnection between experiment and clinic", and integrating experimental operation procedures with clinical diagnosis and treatment processes [14]. For example, through the virtual patient system, the operation process of the "blood pressure regulation experiment" is combined with the clinical diagnosis and treatment process of hypertension, allowing students to simulate the whole process of "blood pressure measurement-drug selection-dose adjustment-efficacy monitoring" in the experiment. It correlates the operation of "intravenous injection of antihypertensive drugs-blood pressure reduction" in the experiment with the diagnosis and treatment behavior of "drug treatment for hypertensive patients" in clinical practice, so as to cultivate students' clinical thinking and theoretical application ability.

3.3. Scientific Research Support: From "Experimental Preparation" to "Innovation Empowerment"

Laboratory technicians should transform from early-stage preparers of scientific experiments to in-depth participants. Supported by AI technologies, they can provide full-process technical support and innovative empowerment for scientific research. They are expected to serve three key roles: experimental design optimizer, data management facilitator, and interdisciplinary collaborator, thereby improving the operational procedures and design logic of research-oriented experiments [9].

(1) Experimental Design Optimizer: By utilizing the prediction and analysis capabilities of AI technology, researchers can optimize the design of scientific experimental protocols, reduce repetitive operations, improve experimental efficiency, and refine key parameters in experimental procedures [6]. For example, in a scientific experiment investigating the effects of different concentrations of propranolol on rabbit heart rate, technicians can use deep learning models to simulate heart rate changes under various drug concentrations, administration intervals, and routes, thereby accurately predicting experimental outcomes. Based on these predictions, key parameters in the experimental workflow can be optimized: the traditional "five concentration gradients" are streamlined to "three core concentration gradients", and "data recording every 10 minutes" is adjusted to "real-time dynamic data collection via AI", thus avoiding unnecessary repeated experiments and enhancing experimental efficiency.

(2) Data Management Facilitator: Take the lead in building a laboratory research data sharing platform, formulate standardized guidelines for experimental data management, and apply AI technology to ensure data security and privacy, so as to realize standardized storage, efficient retrieval and reuse of experimental data, as well as the structured association between experimental procedures and data [11]. Technicians can store the operation procedures, experimental parameters, raw data

and analysis results of different experiments (such as frog heart perfusion, arterial blood pressure measurement and myocardial contraction experiment) in a structured manner, and use AI technology for data classification and organization. Researchers can quickly obtain relevant data by searching "experiment name-operation procedure-indicator type", facilitating scientific research data analysis.

(3) Interdisciplinary Collaborator: Take the initiative to conduct interdisciplinary cooperation with teams in computer science, big data and other disciplines, and jointly develop dedicated AI tools suitable for medical functional experiments, so as to optimize the intelligent links in experimental operation procedures [15]. For example, participating in the construction of a "functional experimental image recognition system", which uses computer vision and machine learning techniques to realize automatic identification and analysis of abnormal cellular features in pathological sections. Meanwhile, participating in the development of an "intelligent evaluation system for experimental operation procedures", which captures students' physical experimental operation actions through cameras, automatically identifies non-standard behaviors in the process and provides real-time prompts, providing technical support for pathophysiological research and experimental teaching.

3.4. Management Function: From "Resource Support" to "Intelligent Ecosystem Construction"

With the digital and intelligent transformation of laboratory management, the management functions of laboratory technicians also need to be upgraded. They should transform from traditional "resource supporters" to "builders of an intelligent experimental ecosystem", focusing on mastering three core capabilities: intelligent resource scheduling, data security protection, and performance quantitative evaluation, so as to realize the whole-process intelligent management of experimental operation procedures [16].

(1) Intelligent Resource Scheduler: Through the AI-powered laboratory management system, realize the intelligent coordination and scheduling of resources such as experimental equipment and virtual simulation stations. Based on experimental teaching plans and students' reservation data, the system automatically allocates experimental resources, monitors resource usage in real time, and optimizes the temporal and spatial arrangement of experimental procedures [16]. For example, in response to students' reservations for the "frog heart perfusion experiment", the system automatically assigns virtual simulation stations and physical experiment benches, and properly arranges experiment batches to avoid equipment idleness and waste. Meanwhile, according to the duration of each experimental procedure, the system intelligently plans the sequence of different experiments, thereby improving the utilization efficiency of laboratory resources.

(2) Data Security Guardian: Establish comprehensive safety management specifications for experimental data, clarify data security responsibilities, and employ AI-enabled technologies such as encryption and access control to strictly protect students' experimental procedure data, sensitive scientific research information in the

laboratory, animal experiment ethics data, and other confidential content, so as to prevent data leakage, tampering, and abuse [17]. For instance, encrypt and store the operational procedures and core data of scientific experiments, and implement a hierarchical access system for "laboratory technicians-research supervisors-students", where only authorized personnel can view and utilize relevant data.

(3) Performance Assessment Implementer: Utilize an AI intelligent scoring model to quantitatively evaluate students' experimental performance from multiple dimensions, including standardization of operational procedures, operational efficiency, accuracy of experimental data, innovative scheme design, and data interpretation ability. Meanwhile, objectively assess the work performance of themselves and the laboratory team, generate detailed performance evaluation reports, and provide a scientific basis for improving experimental teaching and optimizing team work. For example, the AI model scores students in the rabbit arterial blood pressure measurement experiment, focusing on evaluating the standardization of each step: specimen preparation, equipment connection, operation execution, and data recording, so as to accurately identify weaknesses in teaching.

The deep application of AI technology in the entire process of medical functional experiments fundamentally reconstructs the underlying technology, teaching logic, research mode, and management system of experiments. This necessitates a corresponding role transformation for experimenters, forming an inevitable causal relationship between the two. The demand for intelligent device operation and maintenance capabilities stems from AI replacing traditional manual equipment operation and debugging tasks. If experimenters only master basic operational skills, they will be unable to operate intelligent devices such as virtual simulation systems. Therefore, they must transition to becoming operators and optimizers of intelligent devices. The requirement for data analysis capabilities arises from AI technology enabling massive collection and automated processing of experimental data. Traditional manual data interpretation methods can no longer tap into the deep value of data. Experimenters need to become professionals in data analysis and interpretation to provide data support for teaching and research. The necessity of cross-disciplinary integration capabilities lies in the fact that the integration of AI technology and medical expertise is the core of intelligent experiments. Experimenters need to break down disciplinary barriers to combine abstract medical knowledge with intelligent experimental processes, realizing the empowerment of technology in teaching. The role transformation in the teaching support dimension is due to AI technology making personalized teaching possible. Traditional standardized guidance cannot accommodate students' differentiated learning needs. Experimenters need to rely on AI to become virtual experiment designers and intelligent teaching assistants, while building a bridge between experiments and clinical practice, aligning with the core requirement of "combining theory and practice" in medical education. The transformation in the research assistance dimension stems from AI technology revolutionizing the design and analysis modes of scientific research experiments. Traditional shallow participation in experimental preparation cannot meet the needs of scientific innovation. Experimenters need to utilize AI to optimize experimental schemes and manage scientific research data, becoming deep participants in research. The upgrade of management functions is due to the significant increase in complexity of resource scheduling, data security, and performance evaluation after the digital transformation of laboratories. Traditional manual management models are inefficient. Experimenters need to rely on AI technology to build an intelligent experimental ecosystem, achieving refined and efficient management of laboratories. In short, the transformation of AI technology in various aspects of medical functional experiments is the core driving force behind the role transformation of experimenters. The ability upgrade and role reconstruction of experimenters are also necessary conditions for AI technology to fully exert its empowering value in experimental teaching and research.

4. Implementation Pathways and Support System for Role Transformation

Achieving the transformation from traditional laboratory technicians to builders of an intelligent experimental ecosystem requires technicians to systematically enhance their core competencies. At the same time, universities need to establish a sound support system to guarantee the role transformation of laboratory technicians, ultimately realizing the intelligent, personalized and scientific development of experimental operation procedures.

4.1. Four-Dimensional Capacity Improvement Path

Laboratory technicians should carry out targeted training and practice focusing on four core competencies: technology, data, teaching, and management. Through an approach of integrating learning with practice and promoting learning through application, they can achieve all-round capacity improvement, with emphasis on mastering the design, optimization, and guidance of intelligent experimental operation procedures. The specific improvement paths are shown in Table 1.

Table 1. Four-dimensional capacity improvement path for laboratory technicians.

Capacity Dimension	Core Training Content	Practice Mode	Expected Goal
Intelligent Technology Application	Basic operation of AI tools, maintenance of virtual simulation systems, debugging and troubleshooting of intelligent experimental equipment, design of intelligent experimental operation procedures.	Participate in special training on VR/AR experimental technology, learn the digital human system under the guidance of senior technicians, take part in daily operation and maintenance of intelligent laboratory equipment, independently design 1 - 2 sets of virtual experimental operation procedures.	Independently complete the debugging, operation and troubleshooting of various intelligent experimental equipment; autonomously design and optimize hybrid virtual-physical experimental procedures; ensure the stable operation of intelligent experimental systems.

Continued

Data Analysis	Basic theory of machine learning, experimental data modeling methods, application of AI data analysis tools, data visualization, correlation analysis between experimental procedures and data.	Participate in experimental data processing for university research projects, take selective courses on data analysis, independently complete analysis and report writing for small experimental datasets, compare and analyze data differences under different procedures.	Use AI tools for in-depth analysis of experimental data, generate visualized data reports, accurately interpret data patterns and clinical implications, and optimize experimental procedures through data analysis.
Teaching Innovation	Design methods of virtual experimental scenarios, formulation of personalized teaching plans, application of AI-assisted teaching tools, design of differentiated experimental operation procedures.	Independently develop small virtual experimental modules, carry out AI-assisted personalized teaching in pilot classes, participate in university-level virtual experimental teaching projects, design more than 3 sets of differentiated procedures for students with different foundations.	Design at least 3 personalized teaching plans and supporting Procedures for different student groups; proficiently use AI for precise teaching guidance; realize personalized empowerment in experimental teaching.
Intelligent Management	Operation of laboratory AI management systems, intelligent resource scheduling methods, experimental data security specifications, application of AI performance evaluation models, intelligent overall arrangement of experimental procedures.	Be responsible for daily operation and maintenance of the laboratory intelligent management platform, take the lead in formulating laboratory data security management systems, use AI models to evaluate student and team performance, intelligently arrange procedures and resources based on reservation data.	Increase laboratory equipment utilization rate by more than 30%, ensure zero data security incidents, establish a scientific quantitative evaluation system, and efficiently implement intelligent overall scheduling of experimental procedures.

4.2. Construction of the University Support System

As the main entity responsible for medical talent training and the development of laboratory technicians, universities should establish a sound support system in three aspects: training, incentives, and technology, so as to create favorable conditions for technicians to improve their capabilities and transform their roles, and help them master the design and application capabilities of intelligent experimental operation procedures [18].

(1) Establish a personalized and hierarchical training system: Build a diversified training platform featuring "online courses + practical workshops + cross-university exchanges". Offer targeted courses such as Fundamentals of Medical AI, Application of Virtual Simulation Technology, Intelligent Analysis of Experimental Data, and Design of Intelligent Experimental Operation Procedures. Conduct simulation training for intelligent equipment maintenance and experimental procedure design using VR technology, enabling technicians to enhance their operational and design skills in virtual scenarios. Organize regular cross-university ex-

change activities to encourage technicians to share experience and exchange technologies on intelligent experimental procedure design with peers from domestic universities, so as to broaden their technical horizons [19].

(2) Optimize the assessment and incentive mechanism: Incorporate AI technology application ability, intelligent experimental teaching achievements, interdisciplinary research cooperation outcomes, and intelligent experimental operation procedure design achievements into the performance appraisal system for laboratory technicians, and increase the weight of digital and intelligent capabilities in the assessment [9]. Provide rewards and professional title promotion preferences for technicians who develop intelligent experimental tools, design high-quality intelligent experimental procedures, publish interdisciplinary research papers, and achieve remarkable results in AI-assisted teaching, so as to stimulate their enthusiasm for role transformation and innovative vitality [9].

(3) Strengthen technical platform and hardware support: Establish a university-level AI Center for Medical Experiments, and comprehensively deploy advanced equipment such as virtual simulation systems, high-performance data processing servers, AI data analysis workstations, and experimental operation motion capture devices, so as to provide hardware support for laboratory technicians to carry out intelligent experimental teaching, research data processing, interdisciplinary cooperative research, and design of intelligent experimental operation procedures [16]. Meanwhile, allocate special funds for the renewal, maintenance and upgrading of intelligent experimental equipment to ensure the advancement and practicality of the laboratory technical platform.

5. Challenges and Countermeasures

The role transformation of medical functional laboratory technicians in the AI era is a gradual process. Inevitably, many challenges will arise in this process, such as technological adaptation, data security, and ethical disputes, which directly affect the design, application, and promotion of intelligent experimental operation procedures. It requires joint efforts from laboratory technicians and universities to formulate targeted countermeasures.

5.1. Major Challenges

(1) Technical adaptation barriers: Some senior laboratory technicians have long been engaged in traditional experiments with weak digital literacy. It is difficult for them to master new skills such as AI tool operation, data analysis, and intelligent experimental procedure design in a short period, resulting in obvious difficulties in technical adaptation [9] According to survey data publicly released by a certain university in 2025, in a questionnaire survey targeting 38 functional experimenters on campus, 45% of functional laboratory technicians regard "operation of data analysis software" and "design of virtual experimental procedures" as the main difficulties in their role transformation. The fear of technical learning has also affected their enthusiasm for transformation to a certain extent.

(2) Data security risks: The digital storage and sharing of experimental data have significantly increased the risks of data leakage and tampering. In particular, sensitive data involving experimental animal ethics, students' personal experimental privacy, and the core operational procedures and data of scientific research may trigger a series of ethical and legal issues once data security incidents occur [17].

(3) Ethical controversies in teaching: On the one hand, the AI automatic scoring model evaluates based on preset algorithms and standards, which may lead to standard deviations in assessing the standardization of experimental operation procedures, making it difficult to comprehensively and objectively evaluate students' experimental operation ability and innovative thinking ; on the other hand, over-reliance on virtual experimental teaching, which allows students to repeatedly practice virtual experimental operation procedures, may reduce students' opportunities for hands-on practice and weaken their traditional experimental operation skills, which is inconsistent with the practical requirements of medical talent training [14].

5.2. Countermeasures

(1) Implement hierarchical and classified technical training to overcome technical adaptation barriers: Develop a differentiated training curriculum system for technicians of different age groups and digital literacy levels [19]. For senior technicians, offer an "AI Basic Introductory Course" starting with simple AI tool operation and basic maintenance of intelligent equipment, then gradually progress to the design of simple virtual experimental procedures to improve digital capabilities step by step. For young technicians, launch an "Advanced Data Analysis Course" focusing on machine learning, data modeling, interdisciplinary technology integration, complex intelligent experimental procedure design and other high-level skills, giving full play to their digital advantages. Meanwhile, establish a "mentor-mentee pairing" mechanism to encourage mutual learning between young and senior technicians for common improvement.

(2) Build a dual "technology + regulation" protection system to prevent data security risks: Technically, adopt blockchain, encryption algorithms and other advanced technologies to encrypt the storage and transmission of sensitive data and core experimental procedures in the laboratory, ensuring their immutability and traceability [17]. Institutionally, formulate sound safety management regulations for experimental data and procedures, clarify the permissions and processes for data collection, storage, use and sharing, implement data security responsibility to individuals, and conduct regular safety inspections and risk assessments on data confidentiality and procedure security, so as to build a strong safety barrier from both technical and regulatory perspectives.

(3) Establish a hybrid experimental teaching model to achieve balanced development of virtual and physical experiments: Adhere to the principle of "virtual serving physical, technology empowering practice" and build a hybrid teaching

model of "virtual preview + physical operation + AI review", so as to realize the deep integration of virtual and physical experimental procedures [14]. Students first preview procedures and master key points through virtual experiments; then conduct physical operations to improve hands-on skills; finally, AI technology is used to review and analyze their operational procedures and data, identify problems and provide suggestions. Meanwhile, rationally control the proportion of virtual and physical experiments to ensure students' practical skills are fully cultivated and avoid over-reliance on virtual experiments.

6. Conclusions

The advent of the AI era has promoted an all-round and in-depth transformation of experimental teaching and scientific research in medical functional laboratories at universities. Experimental operation procedures have also shifted from traditional "standardized manual operations" to "intelligent and personalized operations integrating virtual and physical experiments". This transformation has driven a profound shift for medical functional laboratory technicians in universities: from "traditional executors of operations" to "builders of an intelligent experimental ecosystem".

This transformation is not a simple supplement of capabilities, but a systematic reconstruction of technicians in four dimensions: technical competence, teaching support, scientific research assistance, and management functions. In terms of technical competence, it realizes the cross-disciplinary integration of traditional experimental skills and AI digital technology, and masters the ability to design and optimize intelligent experimental operation procedures. In terms of teaching support, it moves from standardized guidance to personalized and precise empowerment, designing suitable experimental operation procedures for students with different foundations. In terms of scientific research assistance, it evolves from superficial experimental preparation to in-depth empowerment for scientific research and innovation, optimizing the operational procedures and design ideas of scientific experiments through AI technology. In terms of management functions, it transforms from traditional resource support to the systematic construction of an intelligent experimental ecosystem, realizing the whole-process intelligent management of experimental operation procedures.

As the main entity responsible for medical talent training and the development of laboratory technicians, universities should help technicians break through transformation obstacles such as technical adaptation and conceptual change by building a hierarchical and classified training system, optimizing assessment and incentive mechanisms, and strengthening technical platform and hardware support [18], so as to promote the successful role upgrading of technicians. Only when technicians achieve core transformation can the empowering value of AI technology in medical functional experiments be fully utilized, experimental operation procedures be optimized, and the dual improvement of experimental teaching quality and scientific research level be promoted. This will help cultivate interdisciplinary medical talents with solid theoretical foundation, excellent practical ability, outstanding innovative thinking and clinical thinking, providing solid talent support for the implementation of the "Healthy China" strategy.

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Authors' Contributions

PXC designed and supervised the study, ZYH reviewed the references, ZYH wrote the manuscript, PXC revised the manuscript, ZYH and PXC acquired funding.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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