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A Comparative Study of Clinical Engineering Education and Careers between China and the United States

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***Abstract*—This article takes the undergraduate program of clinical engineering of Diego University of Connecticut and the clinical engineering technology of Shanghai University of Medicine & Health Science as the research object. By introducing and comparing the training level, knowledge system, curriculum design, teaching mode and core curriculum, the clinical engineering technology major of Shanghai University of Medicine & Health Science is aimed at the training of clinical engineering talents of international standards, and provides reference for further improvement of the training level.**

***Keywords*—clinical engineering; educational status; sino-american comparison**

I. Introduction

Clinical Engineering (CE) is the use of modern science and engineering technology knowledge to better serve the clinical research of biomedical engineering. It is developed in the hospital and is based on the whole process of medical equipment management. A discipline of technology, equipment, and economic management issues in hospital equipment modernization.Clinical engineering first appeared in the United States.In 1977, the Biomedical Engineering Branch of the American society of electrical and electronic engineers(EMBS/IEEE) , together with clinical engineering and bioengineering and medical engineering, is listed as three branches of biomedical engineering.[ ].The professional education of clinical engineering is accompanied by the development of science and technology and the advancement of medical technology. A large number of advanced medical equipments have emerged after being used in various clinical aspects of hospitals.

The earliest international clinical engineering education is in the United States.In 1920, the University of Pennsylvania began clinical engineering research and personnel training[ ].Clinical engineering education in the United States is basically a master's degree in biomedical engineering combined with clinical engineering practice[ ], which means that the education received by clinical engineers is mainly done at the graduate level.From past experience, clinical engineering education generally begins with a bachelor's degree in biomedical engineering or a higher degree with a strong engineering background due to strong requirements for the knowledge and hands-on skills of clinical engineers. , followed by doctoral level education, and less training for bachelor degrees[ ].At present, universities in developed countries such as the United States, Japan, and Germany have clinical engineering majors.Almost all medical schools in Japan have clearly named the clinical engineering technology.The United States also explicitly uses Clinical Engineering, such as the Clinical Engineering Graduate Program in the Department of Biomedical Engineering at the University of Connecticut.

Domestically, biomedical engineering education, which began in the late 1970s, has long been an important source of clinical engineering talents in China.In China, the earliest majors in biomedical engineering are secondary education and specialist education.In 1978, the State Science and Technology Commission set up a professional group of biomedical engineering disciplines. Since then, biomedical engineering has developed rapidly in China as an independent discipline.According to incomplete statistics, by 2008, more than 100 colleges and universities across the country have started undergraduate programs in biomedical engineering, of which 24 are medical colleges (including two military medical universities), and the remaining 80 are science or comprehensive universities. In addition to well-known comprehensive key institutions and medical colleges, some local colleges have also opened this major in recent years[ ].In 2001, after a series of investigations and analysis, Shanghai Medical Instrumentation College (now Shanghai University of Medicine & Health Science) cooperated with Osaka High-Tech College in Japan to establish a “Clinical Engineering Technology” program. This is the first in China,"Clinical Engineering" named professional.Filling the blank of domestic clinical engineering technology professional talent training at the specialist level[ ].In September 2017, after 16 years of cooperation in running schools, the “Clinical Engineering Technology” of Shanghai University of Medicine & Health Science was successfully approved and established an undergraduate training program. The professional name is still “Clinical Engineering Technology”.

Through the above introduction to the development of clinical engineering in China and the United States, it can be found that in order to enable clinical engineers to take full advantage of their work, American universities have designed and matched clinical engineers to meet their required knowledge systems and skills of graduate program.However, the clinical engineering education in China started late. Due to the limitations of knowledge and skills, the students trained in biomedical engineering cannot objectively evaluate the advantages and disadvantages of the imported high-tech equipment. In operation, personnel training and maintenance. Maintenance and technical management are all incapable.At present, the training system for clinical engineering and technical professionals has taken initial shape. The training level has gone through the process from scratch, from specialist (higher vocational) to undergraduate. It is internationalized and applied in line with the current needs of clinical engineering and technical talents in China.Therefore, China and the United States have great differences in the clinical engineering professional training system, curriculum, and teaching core content.This article will be based on the clinical engineering graduate education program of the University of Connecticut, the introduction of its knowledge system, curriculum design, teaching model and core curriculum content, to the clinical engineering talents of Shanghai University of Medicine & Health Science to connect with international standards of clinical engineering talents and cultivate the goal and further improve the training level to provide reference for reference.

II. The Status Quo of Clinical Engineering Education in China and the United States Objectives Tree

A. *Education background and training objectives*

According to the above, the clinical engineers of the US medical and health system accept post-graduate education, that is, postgraduate education, which is similar to the admission conditions of American medical schools.Taking the University of Connecticut Clinical Engineering Graduate Program as an example, students have acquired extensive and substantial knowledge of engineering majors at the undergraduate level. These knowledge covers the basic fields of biomedical, electrical, mechanical, and other engineering, but the undergraduate study period is for a professional Clinical engineers are very limited.The clinical environment of American hospitals often requires an engineer to have more diverse knowledge and more professional practice, so becoming a clinical engineer needs to receive engineering graduate education.At the same time, most of the hospital's employees, including doctors, nurses and hospital administrators, have received postgraduate education.The clinical environment of clinical engineers is mainly in hospitals. In order to better serve the entire medical industry, clinical engineers must obtain a master's degree in order to have greater influence in the industry and be more easily accepted by the industry.

Most of the students majoring in clinical engineering technology in China are from high school graduates. They can become clinical engineering technology students only through the National College Entrance Examination (NCEE). Before entering professional studies, most of students have never contacted and studied engineering-related knowledge, and have not practiced any relevant professional fields. This will inevitably lead to the fall of the starting point of professional education for clinical engineering and technical personnel in China.

In China, although various medical devices, medical equipment and medical engineering technologies have been widely used in hospitals, clinical engineering and technical personnel have not formed an overall advantage in hospitals for a long time.There is a widespread phenomenon of “heavy medical work” in medical and health institutions, which will inevitably affect the orientation and training objectives of clinical engineering professionals in higher education institutions. The training level is mostly higher vocational or undergraduate, and the clinical engineers of hospitals have college or higher. Only 30% of the academics,with the rapid development of medical engineering technology, doctors rely more and more on the techniques, means and methods of clinical engineering in the process of diagnosis and treatment. It is imperative to improve the level of personnel training in clinical engineering.

B. *Curriculum design and teaching methods*

The US Clinical Engineering Graduate Program is designed to provide the skills and knowledge that clinical engineers need in a hospital work environment.The University of Connecticut Clinical Engineering program is designed to effectively manage and distribute clinical engineering certificates for the Clinical Engineering Professional Knowledge System, and to consult with more than 500 clinical engineering physicians worldwide every three to four years. The data obtained from the survey forms a clinical engineering knowledge system that includes: 32% technical management knowledge, 17% service management knowledge, 5% product development, testing, evaluation and regulatory enforcement, 8% IT and telecommunications knowledge,10% of equipment user training knowledge, 5% of equipment management knowledge, 11% of risk management and safety knowledge, 11% of integrated management knowledge and 1% of other knowledge.Accordingly, the University of Connecticut created a modern graduate clinical engineering course[i]

The overall curriculum design of clinical engineering in the United States is to find a balance between academic and work practice, and students are recognized through participation in internships.Most of the courses are taught in classrooms in or near the internship hospitals, some of which are taught online in the form of webinars.The University's Department of Clinical Engineering teaches most of the academic programs, and the hospital's clinical engineering director is responsible for day-to-day practice.Students are clinical engineers under the guidance of the Hospital Clinical Engineering Director and other CE department staff. They are familiar with the medical environment and perform typical clinical engineering duties, and integrate the clinical engineering knowledge system with hospital work practices to gain a firmer grasp of what they have learned. During the internship period, each internship will be held once every 4-5 hours of “internship meeting” attended by all students, and the internship content and problems encountered will be exchanged in the form of speeches.Therefore, students are well prepared when they graduate to work in the hospital, and rarely encounter situations or problems that they are not familiar with[ii]

The curriculum design of clinical engineering technology major of Shanghai University of Medicine & Health Science has taken the essence of international clinical engineering technology professional standards and training system, developed a theoretical curriculum system and practical curriculum system that is in line with international standards and conforms to national conditions, and will ideological ethics and professional quality. Professional knowledge and professional ability, humanistic quality and humanistic quality are organically integrated.The entire curriculum architecture includes: 40% general education, 23% professional foundation courses, 14% professional core courses, 5% professional concentration practice courses, 6% elective courses and 12% graduation internship (design) .Among them, the cultivation of students' professional knowledge and professional skills is designed according to the post attributes and post skills of clinical engineers. Students must master certain basic medical knowledge and strong engineering practice skills, and cultivate clinical engineering skills. Throughout the four years of teaching projects.The curriculum architecture is in line with the characteristics of the staged and basic nature of undergraduate education in China. It aims to enable students to master the basic structure, basic principles and basic trends of clinical engineering technology in a limited teaching time, thus forming a certain foothold and vision. To lay a solid professional foundation for stepping into the workplace.

The course design of the clinical engineering technology major of Shanghai University of Medicine & Health Science focuses on the connection with the core business and job skill standards of clinical engineers, and develops a combination of doctors and laboratories around the technologies of cardiopulmonary bypass, surgery first aid and hemodialysis, and forced to change the “infusion type”. And teaching methods that focus on teaching, with "student-centered", use project teaching, simulation teaching, on-site teaching and other methods in the teaching process to improve students' logical thinking ability, innovation ability and self-learning ability.

C. *Core Course Content Comparison*

The core course of the Clinical Engineering Graduate Program at the University of Connecticut is completed in two academic years. The course covers all aspects of the “Clinical Engineering” professional knowledge system designed by the American Society of Clinical Engineers. Some of the major courses are even throughout the learning phase.The seven courses are as follows: clinical engineering foundation, hospital engineering design, human error and medical equipment failure, hospital medical equipment, clinical system engineering, clinical rotation i and ii, clinical engineering interaction.There are 5 courses in these 7 courses including 12 three-hour classes, homework assignments, 1 project per semester, and a paper related to the course, with a midterm and final exam.

TABEL 1 CORE COURSE IN CLINICAL ENGINEERING (MASTER), UNIVERSITY OF CONNECTICUT, USA

Core course name	Course Description	Course content
Clinical engineering foundation	Provide basic concepts in mastering medical technology, establish and operate clinical engineering department, play the role of clinical medical engineering department, and use technical support clinicians	Technology management, technology assessment, acquisition and application, service management, regulations, codes and standards, budget and financial management, security, risk management, equipment performance improvement, personnel management, equipment replacement program, computer maintenance system, new medical equipment acquisition planning
Hospital engineering design	Covering the engineering design challenges found in the health care field, providing the basic concepts of these engineering facilities, and they have direct or indirect links to medical devices that may affect the use of medical devices	Ventilation facilities and indoor air quality monitoring, infection control, medical gas distribution systems, emergency management, hospital power quality and power supply systems, uninterruptible power supply, electrical safety in patient care environments, project management, electromagnetic interference and electromagnetic compatibility, Design of radiation shielding and radiation protection, lighting, real-time location systems, hospital fire protection systems, telemedicine and medical image transmission, hospital buildings and patient care facilities
Human error And medical equipment failure	The basic principles of analyzing medical instruments in medical malpractices, the environment in which medical device users and medical devices are located.It pays special attention to human factors engineering and regards it as an important factor in reducing human error and system engineering failures.	Patient safety, equipment development, role of FDA, human factors engineering, types of human error and classification of medical device failures, root cause analysis, equipment failure modes and their impact analysis, accident and incident investigation, patient injury related to medical devices laws and regulations, operating room fires, electrical surgical burns, laser burns, and tissue damage, anesthesia injuries, infusion equipment accidents, catheter and electrode failures
Hospital medical equipment	Covers 8-10 major technologies currently in use in healthcare.Each technology includes physiological principles, operating principles, key features, technical testing methods and evaluation methods, as well as issues to be considered when managing these technologies.Some courses also include field trips to observe and inspect equipment	Anesthesia equipment, basic principles of medical imaging, X-ray fluoroscopy, magnetic resonance imaging, nuclear medicine cameras, computed tomography and PET/CT, linear accelerators, mammography, ultrasound imaging equipment, laboratory instruments, surgery and ophthalmology Laser equipment, dialysis equipment, cardiac assist devices, surgery and endoscopic video systems
Clinical system engineering	Includes connection and interoperability of medical devices.This includes connecting the medical device to the hospital network, delivering the data to the patient's medical recorder, and connecting the medical device or system to another medical device or system for information feedback and control.	Basic concepts of the network, medical system security and risk management, HL7 and DICOM standards, middleware, connectivity standards and methods, interoperability of medical devices, integration of medical devices, clinical information systems, digital imaging and image storage systems, medical equipment integration project walkthrough
Clinical rotation I and II	Including 24 to 5 hours per day in the clinical environment, clinical engineering rotation, scheduling interns to observe technology / patient / doctor interaction in the hospital	The teaching area includes: surgery/operating room, anesthesia room, intensive care unit, diagnostic imaging room, laboratory, gastroenterology clinic, laser eye clinic, radiology clinic, electrophysiology room, emergency room, clinic, home care Room, dialysis room, electrocardiogram room, physical therapy room, general medical and operating room
Clinical engineering interaction	Internship program for 4 semester 20 weeks, 20-32 hours per week.The interns participate in the actual work as clinical engineering staff and complete the assignment tasks.The school has signed cooperation agreements with 14 hospitals in the University in southern New England, large community hospitals or VA medical centers. Each hospital receives 1-2 clinical engineering interns per year.	Responsible for purchasing, testing and repairing equipment listed in the basic list of medical devices, participating in the implementation of projects, participating in departmental administration, participating in computer maintenance system management, participating in equipment replacement programs, participating in database-related projects, and occasionally participating as representatives Hospital committee meeting and department management meeting

The course of clinical engineering technology of Shanghai University of Medicine & Health Science has learned and absorbed the essence of international clinical engineering technology professional standards and training system, and has formed a theoretical curriculum system and practical curriculum system.

The theoretical curriculum system is based on the knowledge structure requirements of the talents and the technical requirements of extracorporeal circulation, surgical first aid and hemodialysis, including human morphology, basics of disease science, principles and applications of medical statistics, clinical medical profiles, hydraulic and pneumatic techniques, medical ethics, medical equipment technology, clinical skills, medical device quality and safety, clinical engineering technology creative practice and hospital internship 11 professional basic courses and biomedical materials, human biophysical properties principles and applications, biomedical testing technology, medical electrical safety, medicine Clinical diagnostic equipment, life support equipment principles and applications, medical treatment equipment technology 9 professional core courses.The content of professional core courses is to focus on the connection between basic courses and professional courses, focusing on the connection between professional courses and clinical engineering and technical positions. Second, try to carry out integrated teaching, medical integration, general courses, professional basic courses, professional courses and Practice teaching is set around the ability of clinical engineering and technical posts, focusing on the integration of humanities and clinical engineering technology disciplines.

The practical curriculum system is based on the core skills of the operating room, intensive care unit and hemodialysis room. It includes 8 professional concentrated practice courses and practical teaching links integrating experiment, training and internship.The first 1-2 academic year is mainly for on-campus course experiment (training) and comprehensive clinical engineering technology creative practice; the third academic year provides a four-week hospital internship to enable students to experience the clinical engineer's business in the real environment of the hospital, scope of business and job responsibilities; 16th week of graduation internship, including the completion of the graduation thesis.

The school signed an agreement with 12 third-grade hospitals in Shanghai, established 12 off-campus practice bases, conducted “off-campus real-life internships”, and cooperated with top international medical device companies to build five standard training centers: (1) Shanghai University of Medicine & Health Science – Japan NIPRO Hemodialysis Engineering Technology Laboratory; (2) Shanghai University of Medicine & Health Science – Secker Surgery First Aid Engineering Laboratory; (3) Berenger Hemodialysis Training Center – co-constructed with German Braun Company; (4) Surgery and first aid equipment Shanghai public training base – jointly established with Shanghai Medical Devices Co., Ltd.; (5) METRON biomedical testing training room – co-constructed with Norwegian METRON.The five training centers have provided sufficient guarantees for the implementation of the clinical engineering technology professional "in-school simulation scenario training" teaching links.

III. ENLIGHTENMENT TO CLINICAL ENGINEERING EDUCATION IN CHINA

A. *Strengthening applied undergraduate education with the goal of training high-level applied talents*

In the long run, the training objectives of clinical engineering professionals in China should be targeted at masters of clinical engineering technology and even doctoral students.Talent cultivation has always been guided by social needs.Under the background of highly informatized and artificial intelligence of medical institutions, a large number of high-precision, high-tech modern medical equipments have entered clinical use, ensuring the safety and effectiveness of clinical use of medical equipment and ensuring the lives of patients. The demand for safe, high-level clinical engineering technology application talents will become increasingly prominent.

It is estimated that there are about 100,000 clinical engineering and technical personnel working in hospitals at all levels in the country, mainly engaged in the background work of medical equipment purchase, instrument maintenance and medical information system management, rather than the first site actually used in clinical equipment [ ].Most of them have low academic level, professional foundation and business level. They are more focused on job skills, that is, the operation and maintenance of medical equipment, and the problem of aging knowledge is more serious.Undergraduate clinical engineering technology, their medical and engineering foundations are more solid, and their professional knowledge is more broad. In addition to the post-skills of clinical engineering technology, they also have the technical management, technical guidance and technological innovation capabilities of hospital equipment.With the rapid development of modern hospitals, the training objectives of clinical engineering majors in colleges and universities should not only stay at the level of applied undergraduate education, but should be based on practical and strong applied undergraduate education. It is imperative to broaden and enhance the channels for training clinical engineering and technical personnel in China, to adapt to and meet the needs of the development of medical institutions, and to be duty-bound.

B. *Strengthening practical teaching and clinical thinking by means of reform and innovative teaching mode*

Clinical engineering technology, like medicine, is a highly practical discipline. The cultivation of clinical engineering students' practical ability should be the core and essence of the professional education and teaching.Through the understanding of the graduate program of clinical engineering at the university of Connecticut, we can also find that the US clinical engineering graduate curriculum and teaching methods are very focused on the full integration of theory and practice, the implementation of teaching and practice dual tutor system, internship and teaching simultaneously. The students will be able to enter the working state as soon as they graduate from the hospital.

Chinese colleges and universities are based on majors and classes. The current teaching model still hangs on the basic teaching mode of classroom teaching and practical teaching.From the curriculum system of clinical engineering technology undergraduate majors of Shanghai University of Medicine & Health Science, the teaching content mainly emphasizes the instillation of theoretical knowledge and the mastery of basic knowledge. The teaching method is teacher-centered, the proportion of practical course time is relatively low, and the practical content and theory,but the degree of integration is not high.Although the traditional teaching mode has the characteristics of concentration, short-term and high efficiency, the theoretical study has a large proportion and the clinical practice time is short, which will seriously affect the cultivation of students' practical skills and problem-solving skills. The cultivation of talents is unfavorable[ ].

The teaching model of clinical engineering at the university of Connecticut in the United States may provide a reference for how to reform and innovate the teaching model and improve the professional ability and comprehensive quality of clinical engineering technology students in China.First, by increasing the investment in laboratory resources required for clinical engineering undergraduate education, the proportion of experimental courses in the overall curriculum system is actually increased.Strengthen the connection between theoretical knowledge and practical skills, form a synergistic effect of mutual penetration and mutual promotion, and constitute a complete clinical engineering education system, so that students form a comprehensive and holistic concept for supporting the human body and life-related medical operation guarantee system in the learning process. Secondly, with the school's overall resources to strengthen the connection with hospitals and enterprises, the hospital can not only teach students but also fully cooperate with the school to help them develop and set up more reasonable core courses, to provide students with better teaching materials and more professional internship venue.The school employs excellent medical staff from the hospital and engineering and technical personnel of the enterprise to serve as practical course teachers. The director of the hospital equipment department and the enterprise engineer participate in the clinical engineering curriculum setting and practical teaching, and increase the opportunities for students to practice learning in the real medical environment.Third, the use of modern teaching methods such as MOOC teaching, PBL teaching, and CBL teaching to cultivate students' clinical thinking ability and improve teaching results.Teaching methods such as MOOC and PBL have been gradually introduced in the teaching process of domestic medical colleges[10], but they still have a large degree of difference with the United States in terms of the degree of use and teaching effect.At present, the clinical engineering major of Shanghai University of Medicine & Health Science is mainly based on large class teaching. The proportion of class discussion in the big class is relatively low. The independent group discussion and case study are relatively weak, so the chances of student-led are relatively few.Therefore, we should increase the promotion of teaching method reform, and carry out more group-based teaching in the theoretical teaching process to provide students with independent, independent and creative learning conditions.

C. *Promote the development of disciplines with the construction of clinical engineering majors, and promote the realization of standardized training and professional certification*

The American Society of Clinical Engineering (ACCE) is committed to promoting the development of clinical engineering disciplines. The determination of the scope of the clinical engineering knowledge system is one of its main responsibilities. The curriculum of the clinical engineering graduate program at the University of Connecticut is based on this. The knowledge system is built.Since 2002, ACCE has been responsible for the qualification of all clinical engineers and clinical engineering technicians in various medical institutions in the United States[i]

From the source, the discipline is the foundation of the profession, and the discipline construction must precede the professional construction.But for a newly established applied undergraduate college, the school's primary task is teaching and talent development, followed by scientific research.In the construction of schools, we must first do a good job in professional construction before we can promote the construction and development of disciplines.We should start from the professional construction and talent cultivation of clinical engineering technology, improve the clinical engineering disciplines, and enhance the impact and advantages of clinical engineering technology in domestic medical and health institutions[i]

At the same time, the clinical engineering department of medical and health institutions should learn from the experience of the clinical engineer qualification system in developed countries such as the United States, and explore the establishment of a practicing clinical engineer system based on the actual situation of medical institutions in China, and develop a clinical engineer qualification system suitable for China's national conditions. A relatively complete qualification system.At present, the construction of clinical engineering system in China has started.In 2014, the Medical Engineering Branch of the China Biomedical Engineering Society, the Clinical Engineers Branch of the Chinese Medical Doctor Association, and the

Medical Engineering Branch of the Chinese Medical Association jointly agreed to carry out the certification examination for clinical medical registered engineers nationwide[1].Through the standardized management of clinical engineers, attracting high-level professional and technical talents into the field of clinical engineering, and promoting the clinical engineering team to continuously improve the theoretical level and technical level, and provide a steady support for the cultivation of high-level applied clinical engineering talents

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