

Research on the Development of a Teaching Model in Medical Education Based on Principles of Chemical Reaction Engineering

Du Li and Kangle Ding*

¹School of Basic Medicine, Health Science Center, Yangtze University, Jingzhou, Hubei 434023, China

²College of Chemistry and Environmental Engineering, Yangtze University, Jingzhou, Hubei 434023, China

ABSTRACT

This study addresses the core challenges in current medical education—fragmentation of knowledge, disconnection of clinical thinking, and low transformation efficiency—by innovatively proposing and constructing a “Three-Stage Catalytic” teaching model for medical education based on principles from chemical reaction engineering. Adopting an interdisciplinary integration perspective, the research systematically demonstrates the intrinsic mapping relationship between the chemical reaction engineering “input-reaction-output” model and its core elements (reactant concentration, activation energy, catalyst efficacy, transfer efficiency) and the three stages of medical education: knowledge internalization, skill transfer, and catalysis.

*Corresponding author

Kangle Ding, College of Chemistry and Environmental Engineering, Yangtze University, Jingzhou, Hubei 434023, China.

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Introduction

Medical education is facing the triple dilemma of knowledge fragmentation, clinical thinking fragmentation, and insufficient transformation efficiency [1]. In the traditional teaching mode, basic disciplines such as anatomy and pharmacology are separated from clinical practice for a long time, which leads to students' weak diagnostic ability, such as low accuracy of pulse diagnosis and a long period of transformation from theory to practice. However, the mature system regulation thinking and efficiency optimization mechanism of chemical engineering education have significant reference value. The “input-reaction-output” model of chemical reaction engineering maximizes the product conversion rate by accurately controlling the reactant concentration, temperature and catalyst activity. This highly controllable system engineering characteristic just forms a profound mapping with the three stages of “knowledge internalization-ability transfer-teaching intervention” needed to achieve the goal of medical education. It is particularly noteworthy that the curriculum design based on OBE (Results-oriented Education) in the field of chemical industry has verified its effectiveness in cultivating complex abilities in the global engineering education certification system. Therefore, transferring the kinetic principle, transfer process mechanism and catalytic synergy strategy of chemical reaction engineering to the field of medical education not only conforms to the cross-integration trend of new medical construction, but also provides a theoretical basis for reconstructing the paradigm of medical education.

Theoretical Basis: Mapping Model Between Chemical Reaction Engineering and Medical Education

The core of chemical reaction engineering lies in revealing the

kinetic law and transfer mechanism in the process of material transformation. Its four primary factors—reactant concentration, reaction activation energy, catalyst efficiency, and transfer efficiency can be systematically mapped to the key links of medical education. The concentration of reactants corresponds to the input density of medical knowledge, and the low compactness of courses will lead to the decrease of knowledge absorption rate. Reaction activation energy maps cognitive resistance to learning, and the “energy barriers” that medical students need to break through include abstract mechanism understanding (such as tumor signaling pathway) and interdisciplinary knowledge integration obstacles. Catalyst efficiency is directly related to teaching intervention strategies. Transfer efficiency reflects the conversion rate from knowledge to clinical ability, and the virtual teaching and research section improves the efficiency of typical case analysis through inter-school case resource sharing. This paper puts forward a “three-order catalysis” model of medical education, which takes medical knowledge as reactant input, breaks through the activation energy barrier through cognitive schema reconstruction, optimizes the transmission process in clinical scene migration, and finally outputs medical students with accurate clinical decision-making power with the help of catalytic synergy of teaching intervention, thus upgrading the traditional linear teaching mode to a closed-loop system with dynamic feedback.

The Core Framework of the “Three-Stage Catalysis” Teaching Mode

Breakthrough of Activation Energy Barrier-Reaction Kinetic Design of Knowledge Internalization

The process of knowledge internalization in medical education is essentially a complex recombination reaction that needs to break through the cognitive energy barrier. Given the problems of high

cognitive activation energy and high knowledge fossilization rate caused by traditional cramming teaching, the internalization process of medical knowledge is compared to the energy barrier breakthrough mechanism in chemical reaction by innovatively introducing the principle of chemical reaction kinetics, and the cognitive activation energy is reduced by optimizing teaching design, thus significantly improving the efficiency of knowledge transformation. For example, at the molecular level, quantitative methods such as drug-receptor binding free energy calculation are used to transform abstract medical concepts into computable chemical reaction models [2]. At the clinical level, through the analysis of real cases, the dynamic correlation between pathological changes and treatment schemes was established. The highest level of comprehensive decision-making training adopts gradual and complicated virtual cases to realize the systematic cultivation of syndrome differentiation and treatment ability. This step-by-step instructional design makes the process of knowledge internalization conform to the natural law of cognitive development.

In order to effectively support the implementation of this teaching system, a 3D dynamic case simulation system can be used, and students can observe the temporal and spatial evolution of tissue hypoxia in real time by adjusting thrombus position, blood flow velocity and other parameters [3]. At the same time, the cognitive energy monitoring platform developed can quantify the changes of cognitive load in the learning process through biological signal analysis technology. With the application of these tools, the original abstract pathological mechanism becomes intuitive and sensible, which significantly reduces the difficulty of understanding.

Transfer Channel Optimization-Transfer Process Enhancement of Capability Migration

In medical education, the key bottleneck of ability transfer lies in the disconnection between theoretical knowledge and clinical practice [4]. Taking pulse diagnosis teaching of traditional Chinese medicine as an example, under the conventional mode, students can only complete less than 20 simulated training sessions before contacting real patients on average, which directly leads to the low accuracy of clinical syndrome differentiation. Given this core contradiction, this study draws lessons from the theory of mass transfer enhancement in the chemical industry. It innovatively constructs a three-level progressive clinical ability training system. Firstly, the primary transmission channel is established in the virtual simulation platform, and the students complete the quantitative cognitive training of pulse characteristics through the high-precision pulse diagnosis instrument. Secondly, the standardized patient system is introduced to realize the complete closed-loop training from inquiry to treatment decision. Finally, enter the “ultimate reactor” of a real clinical environment. This stepped transmission channel design improves the accuracy of pulse diagnosis and shortens the response time of clinical decisions.

This teaching mode based on transmission process reinforcement is not only suitable for the training of TCM characteristic skills such as pulse diagnosis, but also can be extended to Western medicine clinical teaching. For example, in surgery teaching, through the virtual surgery simulation platform, animal experiment transitions to the three-level training system of clinical practice, which significantly improves the standard rate of surgical operation [5,6]. The innovative value of this model lies in the organic integration of chemical transfer theory into medical education, which provides a new solution path for solving the stubborn disease of medical education that theory is out of touch with practice.

Catalytic Synergistic Cycle Catalyst Design for Teaching Intervention

The effect of teaching intervention in medical education essentially follows the law of the catalytic reaction kinetics, and its efficiency improvement depends on two key elements: the precise construction of catalytic active center and the dynamic regulation of reaction conditions. In view of the core problem of insufficient cultivation of students' innovative thinking in current medical education, it is necessary to promote the transformation of teachers' role from traditional knowledge giver to multi-functional “cocatalyst” [7].

Through the innovative design of the dual tutorial system project, the interdisciplinary catalytic synergy effect can be realized. In the concrete implementation, the chemical engineering tutor guides students to design a liposome drug delivery system by using the principle of nano-preparation, and the clinical medical tutor guides them to carry out tumor targeting analysis and biocompatibility evaluation simultaneously. This dual catalytic synergy mode improves the output of innovative schemes. At the same time, a dynamic catalytic evaluation system based on OBE concept can be established, with typical clinical misdiagnosis cases as reaction initiators, and students are required to use root cause analysis to trace back knowledge chain defects (such as lack of drug interaction mechanism or misjudgment of pathophysiological evolution). Then, under the guidance of interdisciplinary tutors, the diagnosis and treatment path were redesigned and optimized, which is of unique value for improving the quality of medical education.

Practice Path: Transformation Strategy from Chemical Industry Model to Medical Education

Optimization of “Reaction Path” of Curriculum Reconstruction In the teaching process, the medical curriculum system is reconstructed by using the theory of “reaction path optimization” of chemical reaction engineering, and the “reaction selectivity” of the teaching process is improved by eliminating knowledge redundancy. The specific implementation paths include: firstly, the traditional curriculum content is systematically deconstructed, and the mechanical memory module of chemical equation is replaced by the practical case of “clinical reactor”, such as establishing a real-time calculation model of antibiotic administration interval based on the dynamic data of patients' renal function and the formula of drug clearance rate; Or, the project-based teaching of “Clinical Synthesis of Aspirin” is implanted in the medical chemistry course, and students are required to reverse optimize the esterification reaction conditions and parameters according to the cardiovascular and cerebrovascular risk levels of patients. This reconstruction not only realizes the deep coupling between basic chemical knowledge and clinical practice, but also constructs the transformation channel of “molecular level cognition-clinical decision-making ability”.

Construction of “Catalytic Active Center” for Teacher Empowerment

The construction of “a catalytic active center” for teacher empowerment is the key link to promote the reform of medical education [8]. The core of constructing an interdisciplinary teacher matrix with stable “active sites” lies in forming a continuous and efficient collaborative teaching mechanism. By setting up a medical-chemical collaborative lesson preparation group, the advantages are complementary: medical teachers are responsible for providing typical clinical cases (such as the diagnosis and treatment process of diabetic ketoacidosis), while chemical experts

use the principle of reaction engineering to transform them into dynamic acid-base balance reaction models. On this basis, the two sides jointly developed innovative teaching modules such as Clinical Chemical Kinetics to realize a complete knowledge transformation chain from case analysis to reaction mechanism. This kind of deep cooperation can not only improve teachers' interdisciplinary teaching ability, but also form a sustainable knowledge innovation mechanism, which provides a strong teacher guarantee for training compound medical talents [9].

Theoretical Verification and Challenges

Quantifiable Verification System

In the stage of effect verification, we can learn from the core indicators of chemical reaction engineering and focus on two key evaluation indicators based on the theoretical framework of "reaction-transfer-catalysis": first, knowledge conversion rate (number of correct cases of clinical decision-making/total number of training cases), which directly compares the concept of yield in chemical reaction and objectively reflects the efficiency of knowledge transfer and internalization in the teaching process; Secondly, innovation selectivity (number of innovative schemes/number of conventional schemes), which comes from the concept of selectivity in chemical reaction, accurately evaluates the cultivation effect of creative thinking ability in the teaching process through quantitative analysis of typical cases (such as students using nano-carrier technology to solve the problem of blood-brain barrier penetration). These two indicators complement each other, which not only examines the mastery of basic knowledge, but also evaluates the innovation level of thinking, providing a multi-dimensional quantitative evaluation standard for the quality of medical education.

Deep Challenges of Interdisciplinary Integration

In the process of interdisciplinary integration, there is an essential conflict between the fuzzy cognitive characteristics of medicine and the precise modeling requirements of engineering [10]. This conflict is prominently reflected in the quantitative transformation of traditional diagnosis and treatment methods such as pulse condition of traditional Chinese medicine. It is necessary to develop a fuzzy evaluation system of multi-modal data fusion to transform subjective perception into a computable parameter cloud model. At the same time, the uncertainty factors generally exist in medical education, which requires the establishment of quantitative matrix based on interval mathematics to be compatible with the elastic space of subjective evaluation indicators. Teacher coordination and curriculum reconstruction are the key challenges in the implementation process. It is suggested to set up a special zone for cross-innovation of medical workers, and break down discipline barriers through institutional innovations such as double-employment of professors and interdisciplinary identification of teaching reform achievements. In the aspect of curriculum construction, we can build a modular teaching system, develop a configurable teaching reactor platform, establish a standardized interdisciplinary case base, and support the dynamic credit banking system. These measures can not only maintain the professional characteristics of medical education, but also effectively introduce the quantitative advantages of engineering disciplines, and provide institutional guarantees for cultivating new medical talents with systematic thinking and innovative ability.

Conclusion and Theoretical Value

In this study, the three-element mechanism of "reaction-transfer-catalysis" in chemical reaction engineering was innovatively introduced into the field of medical education, and a teaching theoretical model with interdisciplinary characteristics was

constructed. Its theoretical innovation is mainly reflected in three dimensions: first, the cognitive dimension establishes a dynamic model of knowledge internalization based on activation energy threshold theory, which reveals the quantitative relationship between teaching intervention and learning effectiveness; Secondly, the transfer coefficient tensor model of skill transfer is put forward in the practice dimension, which realizes the multi-path optimization of clinical ability training; In addition, the evaluation dimension develops the efficiency functional of teaching catalyst, which provides a quantitative tool for the dynamic regulation of educational process. This model not only breaks through the limitations of traditional empirical teaching, but also provides replicable and verifiable paradigm support for the training of new medical talents with its unique parametric and computable characteristics, which has methodological significance for promoting the digital transformation of medical education.

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