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Original Article

Applying Hands-on Inquiry Learning in Physical Chemistry Teaching Practice to Improve Teaching Quality

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ABSTRACT

Background: Physical chemistry is an important theoretical basic course that supports the development of medicine and pharmacies. Physical chemistry teaching is usually a process of traditional teaching and passive acceptance. The teaching method is singular, and students lack an interest and the ability of autonomous learning. **Objectives:** The purpose of the study is to explore the application of a hands-on inquiry learning strategy blending independent learning based on information resources flipped classroom teaching, the student-centered micro class auxiliary teaching mode in physical chemistry courses to improve student learning outcomes and develop active learning ability. **Materials and Methods:** Eighteen students in the experimental pharmacy major class, grade 2020, were recruited to study in a physical chemistry course that applies hands-on inquiry learning. Formative and summative evaluation were used to evaluate the students' achievements related to active learning goals. After the study was completed, a survey was administered to demongstrate the teaching results. **Results:** Student hands-on inquiry learning performance was positively correlated with the final scores. The results show that comprehensive scores of students of 2020 grade (experimental group) are significantly better than grade 2019 students (control group); in particular, the theoretical scores of 2020 grade students are better, and the data are significantly different. The questionnaire showed that most students believed that hands-on inquiry learning strategy blending independent learning improved their high-level cognitive skills and enhances their social cohesion and sense of responsibility. **Conclusion:** The hands-on inquiry teaching strategy developed in this study effectively improved students' performance in formative and summative assessment, and provided a reference basis and informative entry point for the implementation of active learning strategy in higher pharmaceutical education.

Keywords: Hands-on inquiry learning, Higher pharmacy education, Active learning, Teaching strategy, Problem-based learning.

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INTRODUCTION

Physical chemistry comprehensively explores the law of chemical change by analyzing the principles and methods of physics, which is an important basic course for pharmacy undergraduate students.[1,2] The curriculum characteristics of physical chemistry include the following. (1) Basic theory: Physical chemistry involves almost all the theoretical basis of the chemical change process and is a necessary knowledge system to guide students to fulfill follow-up studies of professional courses. (2) Practical application: With the mutual penetration and connection between relevant subjects, there are an increasing number of combinations of medicine and physical chemistry. For example, many studies of new medicines involve the principles of physical chemistry, including natural compound extraction and separation, the synthesis of new medicines, and drug delivery systems. Physical chemistry has become an important theoretical basis to support the development of medicines and pharmacies.[3,4]

Traditional physical chemistry teaching is mostly based on classroom teaching, and experimental courses are mostly confirmatory or comprehensive experiments. For students majoring in pharmacy, it is difficult to achieve an in-depth understanding of the principle only by learning knowledge from the physical chemistry classroom.[5] Many students are more passive in learning, and it is also difficult for teachers to teach knowledge. An investigation on the teaching effect of the physical chemistry classes of the Pharmacy Specialty at our university in the last five years shows that there are mainly the following four problems in the teaching process: (1) Due to the abstract principle, single teaching method and many theoretical explanations, the course is difficult to learn, which makes it difficult for traditional teaching methods to capture students' attention and spark their innovative thinking. (2) The content of the experimental course

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is not closely related to other specialized courses of pharmacy, disconnected from scientific research and practice, lacked the application of advanced teaching methods. (3) Students lack the ability to internalize knowledge, flexibly apply their knowledge, draw inferences from one instance, actively think and guide production practice with theory. (4) Students have great pressure to learn courses and a high fear of difficulties, and some students are even in a passive learning state. In view of the above problems, there is an urgent need to explore and practice a new teaching method of physical chemistry for pharmaceutical undergraduates at our university, carring out curriculum teaching reform, and examining how to promote active learning teaching methods for students so that they can solve some practical problems applying their learned knowledge. In other words, it is crucial to study how to improve the quality and effects of education so that it has good promotion and reference value.[6]

Hands on inquiry learning is an open teaching system originated in the early 20th century.[7-9] Its core is to integrate innovative education into the teaching process, break the traditional teaching mode that is classroom-, textbook- and teacher-centered, and combine the classroom teaching of professional basic knowledge with the themes of production practice, scientific research examples and the scientific frontier. The main lecture content is combined with the content of other professional courses, meanwhile, teachers' guidance is combined with students' autonomous learning to form an autonomous and exploratory learning activity for students under the guidance of teachers. In the learning process, teachers and students explore and develop together.[10] Driven by strong problem-solving motivation, students actively apply learning materials and learning resources, carry out independent explorations, interactive discussions and cooperation, obtain direct experience through personal practice, develop an innovative spirit and scientific attitude, master the methods of learning, and cultivate students' ability to use knowledge and re-create what they have learned in practice. Therefore, the research teaching method shows obvious differences from the traditional teaching method (Table 1).

In the process of carrying out research teaching, foreign universities have adopted various forms and different modes. Based on cultivating the research consciousness of teachers and students, American colleges and universities have constructed a series of seminar courses, including special research for freshmen and research topics for older students.[11-14] They provide different research teaching and learning modes according to the characteristics and types of students.[15] German universities have the project-based learning method for student groups, which has high requirements for students' self-study ability.[16] Students' self-study needs to be carried out around the selected projects. Students' self-study is combined with teachers' formal teaching to promote the smooth completion of the project. Australia university teaching focuses on cultivating students' autonomous learning, cooperative learning ability and communication ability to form a sense of responsibility.[17] At the same time, students need to have a sense of questioning and criticism and carry out effective research-based learning with the concepts of research and examination. The forms of research teaching in Canada are flexible and diverse, and they focus on the extension within and outside the classroom.[18] These techniques adopt the theme circulation method to enable students to form new problems with research consciousness when analyzing and solving problems to cultivate their research talent with problem consciousness.

Since the research teaching method was put forward in Chinese colleges at the end of the last century, many college teachers have carried out research teaching reform and attempted some courses. For example, since the implementation of the research-based teaching method in 2015, the pharmacy major at Chengdu University has significantly improved not only the knowledge level of students in many courses but also their ability to solve practical problems and make great progress in their innovation ability, which has laid an important foundation for students to better and more quickly adapt to pharmaceutical jobs in the future. In 2020, the Department of Chemistry of Nankai University launched hands-on inquiry learning research for physical chemistry undergraduates, and invested in the construction of research-based teaching case database and hands-on inquiry learning combining experiments and scientific research projects. However, researchers found that there are still some problems in the implementation of this teaching method, such as the difficulty in the design of special topics and cases in research teaching.[19] It creates higher requirements for teachers' awareness of curriculum innovation and their classroom organization ability. It also has higher requirements for students' learning process because it requires students' active cooperation in the entire process. How to evaluate the effect of the applied research teaching method is still a problem that requires attention in the implementation of the teaching method.

MATERIALS AND METHODS

Protocol

In the teaching process of physical chemistry for the four-year pharmacy major in our university, we conducted independent learning based on information resources flipped classroom teaching, the student-centered micro class auxiliary teaching mode, the network-based self-designed experimental teaching mode and other independent learning modes and compared the comprehensive scores of students of this course with the traditional teaching method of our university in 2021 to evaluate the application effect of the autonomous teaching mode. The teaching team of this course carried out teaching practice for three months, which was approved by the Academic Affairs Office of Air Force Military Medical University (Xi'an, Shaanxi). The faculty team developed a curriculum plan for inquiry teaching,

Table 1: The main differences between hands-on inquiry learning and traditional teaching methods.

List of the main differences	Traditional teaching method	Hands-on inquiry learning
Teaching Aim	Aim at students' mastery of knowledge and skills.	Aim at cultivation of students' comprehensive ability, knowledge understanding and mastery.
Teaching Mode	Teachers give lectures, students listen passively, and the process of teaching and learning is mainly completed in class.	Students actively acquire knowledge after class and internalize the knowledge.
Teacher's Role	Teachers collect and process data and impart knowledge, with high requirements for teachers' professional knowledge.	Teachers mainly guide students on how to acquire knowledge, with high requirements for teachers' comprehensive ability.
Learning Process	Students listen passively and finish their homework after class.	Students collect and analyze data, write papers, discuss after class, and use their new knowledge to solve problems.

including teaching weeks, teaching time and teaching topics (see Table 2), and distributed it to participants.

Participants

Eighteen students in the experimental class of the pharmacy major, grade 2020, were recruited to study the physical chemistry course that applied the hands-on inquiry learning mode. The participants were not informed about the study prior to its commencement.

Measures

In the teaching of physical chemistry theory course, the implementation of research-based teaching methods mainly relies on the reasonable setting of problem-solving theme cases. Teachers create situations and raise problems according to appropriate case themes closely related to the course content. From the perspective of students themselves, teachers guide students to think independently, master knowledge and gradually learn to use knowledge flexibly to solve problems through the processing of learning materials, group cooperation and classroom discussion.

Content of the subject case for hands-on inquiry learning

According to the teaching chapters specified in the teaching plan of the physical chemistry course of the pharmacy specialty, we systematically identified and improved the existing scattered special cases to form special cases suitable for research teaching. When sorting and selecting subjects, we met the requirements of extensive and novel content and considered the pertinence, typicality, inspiration and intersection of the content with other disciplines of pharmacy. This subject establishes five research teaching topics (Table 1), including thermodynamic theory, kinetic theory, electrochemical basis, chemical equilibrium and phase equilibrium, surface phenomena and colloids. Each part selects 3-5 topics to form a case base as follows.

The promotion of hands-on inquiry learning based on problem solving

According to the teaching content, we select appropriate case topics from the special case database, provide some progressive problems to be solved, assign learning tasks before class, and require students to take problem-solving as the goal, and first read the teaching materials. Finally, the students fully use the network and information resources, such as literature reviews, network queries, micro classes, MOOC, etc. Students search the knowledge principles related to physical chemistry in production and life, study and discover the chemical laws hidden in problems and learning resources to obtain new knowledge, new methods and emotional experiences, and improve their ability to obtain information and process, sort out and apply information.[20]

(i) Teachers create situations and ask questions. Teachers show relevant examples in class, clarify learning tasks and propose subject problems to be studied. Students can also independently design subject problems to be explored according to the teaching content.

(ii) Students engage in research-based learning with teachers' supervision and guidance. Teachers organize learning interest groups, select and determine the theme of exploration, and formulate a plan of theme learning (including determining the objectives, the group division of labor and planning progress).

(iii) Teachers provide resource catalogs, relevant websites, data collection methods and other ways to learn the topics, and students explore and find solutions to problems independently. In this process, teachers mainly play the roles of supervision and guidance, communicate with students in time, understand the learning progress and difficulties, and help students complete the corresponding tasks such as a literature review, sorting out ideas and drafting high-quality outlines on time to finally form a research report related to the theme.

(iv) Teachers organize views and promote the internalization and transfer of knowledge. After students study after class for a

Table 2: Research teaching topics of the physical chemistry theory course.

Content of course	Hands-on inquiry learning topics
Thermodynamic theory	The application of the first law of thermodynamics in chemical change, the physical significance of entropy, the thermodynamic criterion of chemical reaction direction and limit.
Dynamic theory	The determination method of the first-order reaction half-life of drug decomposition, the influence of temperature on the prediction of drug storage life, and the general method of formulating chemical reaction process.
Electrochemistry	Thermodynamics of reversible battery, generation of electrode potential, electrochemistry of biomolecules.
Chemical equilibrium and phase equilibrium	Thermodynamic conditions of chemical equilibrium, preservation of unstable antibiotics in aqueous solution, phase equilibrium principle of distillation and distillation.
Surface phenomena and colloidal chemistry	Hydrophilic lipophilic equilibrium value of surfactant, adsorption of solid in solution, stability and aggregation of sol.

period of time, teachers organize and guide students to publish their own learning and research results on the questions raised in class. Teachers should guide students to ask questions, encourage questioning, and direct students to further in-depth discussion. At the same time, students are encouraged to record emerging problems for further exploration and research and summarize the situation of theme learning.

(v) Students submit a summary to deepen their understanding. Students can be required to summarize the contents of their research and learning in a variety of ways, such as writing small summaries, or investigation reports, drawing mind maps, etc., which deep the knowledge learned in the combination of theory and practice. This improves their ability to use knowledge of solving practical difficulties, and at the same time, urges students to give attention to the practical application of learning in their future work and lives.

Data analysis

The evaluation of the learning effect of the inquiry teaching of physical chemistry is achieved by combining both the comprehensive physical chemistry scores of the participants and their answers to questionnaires.

(i) Comprehensive score evaluation: The comprehensive physical chemistry score is usually composed of a theoretical score (80%) and an experimental score (20%), of which the theoretical score is composed of the final examination score (60%) and the written homework score (20%). The experimental results include the experimental report (10%) and experimental attitude and hands-on operation ability (10%). By comparing and analyzing the comprehensive physical chemistry scores of the undergraduates of 2020 grade who adopt the autonomous teaching mode with the comprehensive scores of undergraduates of 2019 grade who did not adopt the teaching method in the previous year, this paper discusses the role of the inquiry-based autonomous learning mode in improving the teaching effect.

(ii) Questionnaire evaluation: After the course, a questionnaire was distributed to the participants of 2020 grade. The questionnaire was designed by nonsubstitute teachers in the department of chemical pharmacy of Air Force Military Medical University and the students completed it anonymously. A total of 18 questionnaires were distributed, including 1 invalid questionnaire, and the effective recovery rate was 94.4%.

(iii) Statistical methods. Office Excel 2013 and social science statistical software SPSS 19.0 were used to calculate the data statistics on the questionnaire and assessment results to provide a basis for the scientific evaluation of the subject. The measurement data obtained were expressed by a t-test, $p < 0.05$, and there were significant differences in the data.

RESULTS

Comparison of the examination results

The comprehensive scores and subscores of the 2020 (experimental group) and 2019 (control group) graded students are shown in Figure 1. Students' understanding and mastery of physical chemistry knowledge is reflected in their theoretical score (Figure 1A) and experimental score results (Figure 1B) and experimental results. The self-study ability, knowledge integration ability and the ability to analyze and solve practical problems of 2020 grade undergraduates have been improved, which is better than the traditional teaching mode of 2019 grade undergraduates.

Comparison of formative achievement

The effect of the application of an independent teaching mode to physical chemistry teaching practice is evaluated through a questionnaire. The evaluation content specifically includes the cognitive effect of students on the learning content, the investigation of students' learning satisfaction with micro courses, the teaching effect of a flipped classroom, and the improvement of students' own experimental skills and scientific research interest with the independent experimental content. To ensure the objectivity of the survey data and the fairness of the results, the course team studied and designed the course questionnaire, which students completed anonymously and returned; the questionnaire was counted by relying on the comprehensive network teaching platform. There were 18 respondents and 1

Table 3: Questionnaire and results for physical chemistry based on autonomous studying mode (18 questionnaires were collected).

Serial number	Questionnaire content	Number of students choosing this item	Proportion (%)
1	Compared with traditional teaching methods, I prefer the teaching mode of network self-study and flipped classroom.	16	88.9%
2	Flipped classroom improves the interest in this course.	15	83.3%
2	Micro class deepens the understanding and mastery of difficult knowledge points.	17	94.4%
4	Group discussion has increased interest in autonomous learning of this course.	16	88.9%
5	The exchange and discussion with teachers and students deepened the understanding of theoretical knowledge points.	15	83.3%
6	The ability of self-study and drawing inferences from one instance have been improved.	17	94.4%
7	The ability to think independently and analyze and solve problems has been improved.	15	83.3%

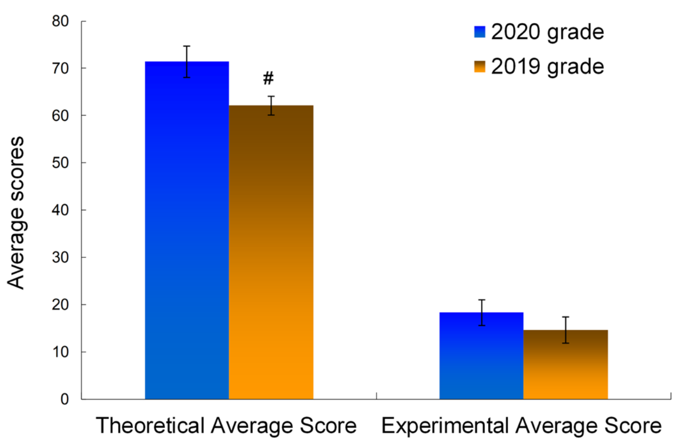

Figure 1: Comparison of theoretical scores and experimental scores of physical chemistry between 2020 grade and 2019 grade undergraduates.

Data are presented as the mean±SD, n=18. $^{\#}p < 0.05$ compared with the scores of 2020 grade.

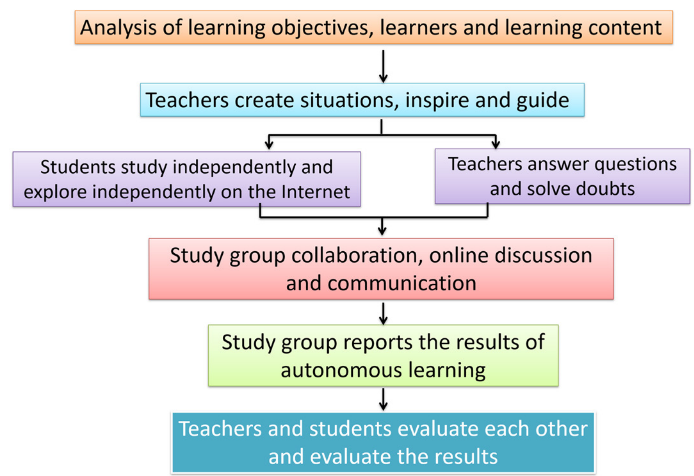

Figure 2: Inquiry learning process based on Information Resources.

invalid questionnaire. The effective recovery rate was 94.4%. The questionnaire and survey results are listed in Table 3.

From the results in Table 3, questions and 2 reflect students' recognition and acceptance of the flipped classroom form to improve the learning effect and stimulate students' learning enthusiasm to a certain extent. As seen from questions 4-6, the students believe that the micro class is conducive to improving learning efficiency and deepening their understanding and mastery of difficult knowledge points. Question 7 reflects that 83.3% of the students believe that adopting various forms of autonomous learning modes can improve the learning effect of medical organic chemistry, which is mutually confirmed with the improvement of students' comprehensive scores.

DISCUSSION

A revolution in information technology bring a great impact on higher education worldwide in recent years, which resulted in great changes to inherent educational objectives, educational views, educational means, educational content and educational organization forms.[21,22] In the past 20 years, the inquiry learning methods has become the central focus of higher education teaching reform in US, England, Australia and other European countries.[23-26] Similar to the teaching reform of western countries, educational reform in China is also exploring to take inquiry education based on the information technology as the goal and way of educational reform.[27] How to integrate advanced information technology into teaching practice, according to the characteristics of physical chemistry teaching and students' learning characteristics, and how to use new teaching strategies to construct the inquiry independent learning mode of the Physical Chemistry Course considering information technology is of great significance to improve the efficiency and quality of physical chemistry education and enhance the innovation ability of students.

The inquiry independent learning mode requires students to read the content of textbooks, fully use network courses and information resources as a supplement to textbook knowledge, and perform inquiry learning.[28,29] This method lets students explore independently, become the main body of learning, study and discover the chemical laws hidden in problems and learning resources, so as to obtain new knowledge, methods and emotional experiences that improve students' ability to independently obtain information and process, sort and apply it. For example, before teaching the chapter on colloids, we put forward the learning tasks (composed of several questions) and requirements of this chapter and put the questions in the discussion area of the powerpoint or physical chemistry network course. Through online courses, students can independently learn relevant content according to the teacher's question outline or browse websites or resources related to the learning content to seek answers to questions.[30,31] After students study independently for a period of time, teachers organize flipped classroom teaching. In this process, teachers guide students to ask questions and question each another, and teachers encourage students to record new problems for further exploration. According to the problems that exist in students' understanding of the content, teachers explain some difficulties and key points, summarize the learning content of the whole chapter, select typical exercises for classroom tests, assign homework questions, and test students' learning effect. At the same time, high-quality homework can promote students' ability to use theoretical knowledge to solve practical problems, and achieve the purpose of knowledge transfer and deepen their comprehensive understanding of knowledge (Figure 2).

The feedback results of the questionnaire show that this teaching mode of autonomous learning combined with a flipped classroom can make the knowledge learned by students more systematic, more generalized and easier to learn and use flexibly. Moreover, it can better reflect the main position of students, which is conductive to take advantage of the initiative of students in the teaching process. In contrast, the leading role of teachers lies in their "guidance". The unity of imparting knowledge and developing intelligence is conducive to the development of students' intelligence, and it cultivates their adaptability, selectivity, competitiveness, cooperation and participation; it also promotes students' in-depth understanding of what they have learned, and it meets the characteristics of in-depth learning.

The teaching content of chemical thermodynamics involves many new concepts, new terms and new laws, which is difficult for some students to master, understand or apply, especially easy to confuse. After students' systematic learning in the classroom, teachers design a series of questions according to the knowledge points that students need to master in the classroom. Students are invited to view micro videos, participate in Q&As and discussion, and relearn the knowledge points of the course through online literature reviews, online learning, the internet and other channels. The use of micro course resources can visualize the more abstract knowledge in physical chemistry, and teachers can help students expand their learning and transfer and application of knowledge through few but precise exercises aimed at key points, difficulties and puzzles, so that students can better understand the chemical reaction rules of compounds and gradually build an organic knowledge framework. It is worth mentioning that in teaching, we also combined the relevant scientific research work of our teaching and research office to strengthen the combination of chemistry and medicine. From the feedback results of the questionnaire, it can be seen that the cutting-edge science and technology content involved in the micro class video or the scientific research content related to the teaching and research office can inspire students' interest in learning and receive good learning results. After class, we set the learning expansion resources closely related to the teaching content as expansion tasks and placed them on the network course platform to effectively guide students to apply the knowledge points mastered in the classroom to real life. In this way, students can use the learned knowledge and skills to solve practical problems, which effectively improves students' autonomous learning ability and makes their understanding of knowledge more specific and vivid.[32] With such methods, textbook knowledge can truly be transformed into students' own knowledge system to realize the consolidation and expansion of their knowledge or skills.

CONCLUSION

The implementation of this model adopts the voluntary combination of students. Each cooperation group selects the topics of interest, helps and learns from one another, shares resources, reasonably divides labor and assumes its own responsibilities. In the discussion and communication stage, we fully utilize each person's strengths and opinions, allowing them to express their opinions through mutual inspiration, communication, and supplementation between groups, in order to improve the research and learning outcomes of each group. Through the integration of various learning resources and information, students expand their knowledge and write small research papers or reviews. This inspires their strong interests in learning, connects theoretical knowledge with actual production and life, closely combines chemical knowledge with medicine and pharmacy, and promotes the cultivation of students' scientific research ideas. This hands-on inquiry learning mode can improve the ability of students to integrate knowledge and to analyze and solve practical problems, which fully reflects students' autonomy, initiative and creativity in learning. This method is conducive not only to enhancing teaching interaction and promoting the reform of traditional teaching methods but also to improving teachers' teaching quality and promoting the improvement of teaching quality and level.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ABBREVIATIONS

MOOC: Massive Open Online Course; **Q&As:** Question and Answer.

SUMMARY

This study develop a hands-on inquiry learning strategy in a physical chemistry course, blending independent learning based on information resources flipped classroom teaching, the student-centered micro class auxiliary teaching mode, the network-based self-designed experimental teaching mode and other independent learning modes and compared the comprehensive scores of students of this course with the traditional teaching method of our university in 2021 to evaluate the application effect of the autonomous teaching mode. The results show student hands-on inquiry learning performance was positively correlated with the final scores. On the surveys, a large majority of students reflected that working on instructor-posed questions improved their higher-order cognitive skills, social cohesion, which made them understand the sense of accountability. The hands-on inquiry teaching strategy developed in this study was effective in improving student achievement in both formative and summative assessments, which provides an accessible and informative entry point for implementing active learning in higher pharmacy education.

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