Exploration and Practice of a Basic Experimental Teaching System Oriented by College Student Innovation and Practice Competitions

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Keywords: Open Laboratory, Undergraduate Projects, Multi-level Experimental Teaching Model, Research Innovation

Abstract: This study explores the reform of a multi-level experimental teaching mode oriented by the basic medical innovation forum and experimental design competition for college students. Since 2013 in medical schools, clinical medicine professional teaching classes announced the experiment open arrangement, requiring the students to sign up voluntarily, the establishment of an innovative experimental teaching system, the biochemical experimental project is divided into different types of experiments, such as open experiments, comprehensive design experiments, and so on, and the innovation element is integrated into the experiments in all aspects. After completing the first stage (open experiments) as well as the second stage (comprehensive design experiments), 10-20 students are screened into the next stage of study-college students' innovation project experiments-each year according to their completion status, and students suitable for the competition are finally screened out. The survey results show that all students are satisfied with the content and progress of the open experiments, and believe that they can improve their problem-solving ability, contribute to the cultivation of innovation and hands-on ability, and stimulate the interest in scientific research; In addition, the feedback when facing the examination retest and employment interview shows that the trained students can easily cope with the scientific research and practical application problems in the retest and interview, and there are even those who have a reverse attack in the examination retest, and the rate of the previous examinations is as high as 98% or more. The innovative experimental teaching system established with the orientation of the Basic Medical Innovation Forum and Experimental Design Competition can effectively cultivate students' innovative ability and stimulate students' interest in continuous innovation, and the trained students can easily cope with scientific research and practical application problems.

1. Introduction

Higher education institutions bear significant responsibility for nurturing innovative talent, and enhancing the research and innovation capabilities of medical students is the primary task of medical schools in the future, which has also presented new challenges for contemporary medical education models. Currently, the mainstream model of medical education in China still relies heavily on teachers imparting knowledge, with students self-studying as a supplementary approach. The classroom teaching model is still the primary means for medical students to acquire knowledge, while experimental teaching practices have not received genuine and effective attention or an elevated status within the basic medical curriculum system[1-2]. Surveys indicate that medical students lack sufficient understanding of certain cutting-edge and innovative knowledge, and are not aware of the significance of experimental courses in scientific advancements and innovation. More than half of the students can only acquire relevant knowledge through online courses like MOOCs, technological innovation programs, educational forums, and online resources to obtain relevant knowledge[3]. Therefore, building upon the current modes of teaching, utilizing avenues both within and outside the curriculum

  DOI: 10.25236/meeit.2024.039

to foster multiple pathways that encourage students to actively participate in scientific-practical activities is an important aspect of nurturing research and innovation capabilities among medical students, and establishing an innovative educational and training system for medical students[4].

The main bottleneck in cultivating innovation capabilities among medical students lies in their lack of intrinsic motivation to participate in innovative activities and their ability for independent thinking. Therefore, creating a vibrant atmosphere for research and innovation, stimulating students' intrinsic motivation to engage in innovative activities, and fostering their awareness of innovation as well as their ability to think independently and solve problems are the core elements in building an innovative education system for medical students[5].

Based on a teaching method with "a core focus on problem-solving and research competitions, with students as the main focus", an innovative talent development model that combines teaching and research aims to enable students to 'enter the laboratory earlier, join projects faster, and become part of a team earlier on, thus enhancing students' original innovation spirit and research capabilities'. To achieve this objective and fully engage students' proactive enthusiasm, stimulate their innovative thinking, and ignite their passion for experimental exploration, we will deepen the reform of experimental teaching from the perspective of student laboratory courses. We will establish an innovative experimental teaching system and categorize basic biochemical experiments into different types, including open experiments and comprehensive design experiments, and infuse innovative elements into every stage of the experiments. Starting from the basics, progressing to the advanced, and centering on cultivating students' innovation capabilities, we aim to inspire students to continually innovate.

2. Literature and Methods

2.1. Research Context

Starting from the 2013 academic year, experimental open schedules were announced for clinical medicine majors in a certain medical college in China. Adopting a voluntary student registration method for these experiments, after completing the first stage (open experiments) and the second stage (comprehensive design experiments), students were selected for the next stage of learning based on their performance (evaluations included topic selection, design, material application, pre-experiments, formal experiments, completion report writing, dissertation defense, and thesis writing). Each year, 10-20 students are selected to advance to the next stage of study - undergraduate innovation project experiments.

2.2. Research Methods

Before the experiments, the teaching and research department held collective discussions with the laboratory. Taking into account the characteristics of different clinical medicine majors and the existing laboratory conditions, they determined the specific content to be explored in open experiments and the locations for these experiments. The arrangements and requirements for open experiments were communicated to students in advance through various means such as online platforms, notice boards, and announcements from course instructors. Students were invited to voluntarily sign up for participation and were expected to independently complete the experiments during their free time.

2.2.1. Open Experiments

The first level of open experiments is the observation stage. Molecular biology techniques have become a key technology in the life sciences since the genomic era of the 21st century. Therefore, we offer commonly used molecular biology techniques in research, such as "protein isolation, extraction, and identification" and "SDS-polyacrylamide gel electrophoresis," as comprehensive undergraduate experiments, and designate them as open experiments. In this experimental process, we incorporated the following innovative elements: First, we guided students to participate in experiment design and preparation work, involving students in experiment design and preparation, thus allowing them to gain a deeper understanding of the experimental principles and objectives as well as a more flexible grasp of the techniques. For example, in the experiment designed to measure protein content, students can try to derive preliminary experimental methods based on the properties of proteins they have learned in textbooks such as designing electrophoresis methods based on the charged nature and amphoteric dissociation of proteins. They can also design methods to determine protein content by monitoring changes in absorbance based on the optical properties of proteins. Furthermore, they can explore how to separate and purify proteins using techniques like chromatography and molecular sieving, considering differences in protein molecular size and charge. With guidance from the teacher, students progressively refine their experiment designs by consulting relevant literature, and this part of the work should be reflected in their pre-experiment reports. This approach not only stimulates students' desire for knowledge, exploration, and innovation but also enhances their practical skills. It effectively reinforces their understanding of biochemical theory and increases their interest and motivation to learn. Additionally, it cultivates students' ability to access and utilize literature, laying a solid foundation for their future research work. Second, the preparation work for participating in the experiment is equally important. There is a wide variety of biochemical reagents, including some that are highly toxic, and preparing reagents requires the correct concentration ratios and steps. Only by participating in the preparation can students understand the properties and uses of the reagents. Finally, through the setup and placement of laboratory equipment, students not only gain an in-depth understanding of their functions and uses but also develop a profound appreciation for the rules of equipment usage and routine maintenance. This greatly enhances their practical laboratory skills.

The second level of open experiments is the simple design stage. After students develop an interest in experimental operations, they can begin with simple open experiments. These experiments primarily revolve around the establishment of models from previous observation experiments and mainly involve the validation of theories related to protein isolation and purification, as well as the use of Western Blot to detect protein expression levels. Learning at this stage is primarily conducted through the PBL-style interactive class, where each group of students initially proposes research directions that interest them, then the group members collectively review literature and explore preliminary methods to address their proposed questions and hypotheses, and proceed with a simple experimental design. Once the simple experimental designs are completed, one student is selected to present the entire experimental design process using a PowerPoint presentation format. The teacher provides feedback and suggestions, allowing 1-2 weeks for revisions and improvements. Afterward, the experiments are conducted, and conclusions are drawn. Following repeated verification of the experimental conclusions, students can also engage in virtual simulation experiment designs based on these simple designs and thus, this approach aims to further stimulate students' strong enthusiasm and interest in research.

2.2.2. Comprehensive Design Experiments

After one semester of simple experimental design, students have mastered the basic skills of biochemical experiments. They can now proceed to the comprehensive design stage, where experiments are mainly centered around our university's undergraduate research topics. The experimental process includes selecting topics, designing experiments, requesting materials, conducting preliminary experiments, performing formal experiments, writing completion reports, defending the work, and writing research papers, among other stages. The selection of topics for comprehensive experiments can be based on students' interests and expertise. It is typically decided by the members of the experiment group, considering the research field of the supervising teacher, after discussions. Once the topic is determined, the experimental design begins. With the foundation of their previous learning, students in this stage continue to complete tasks such as literature reviews, group discussions, PPT presentations, and receiving feedback from the supervising teacher. This approach emphasizes student agency. Finally, student-centered groups submit their research topics as part of their application for our university's undergraduate research project. Once granted project funding, students can utilize the resources of the research laboratory to conduct their research, achieving a true 'learning by doing' teaching outcome. The implementation of comprehensive design experiments allows students to truly understand and master the basic processes of scientific research, encompassing literature review, topic selection, experimental design, and experimentation. This undoubtedly establishes a solid foundation for students' future innovative scientific research.

2.3. Evaluation Methods

An anonymous questionnaire survey was conducted annually to students participating in open laboratory experiments. The survey primarily focuses on the satisfaction level of students involved in open experiments, their participation in research topics, and a questionnaire related to graduate school entrance exams.

3. Results

The survey results (see Table 1) indicate that all students are highly satisfied with the content and progress of open experiments. They believe that these experiments enhance their problem-solving abilities, contribute to the development of innovation and hands-on skills, and stimulate their interest in research. Additionally, 75% of the students feel that open experiments increase their proactive engagement in theoretical course studies and help solidify their understanding of the subjects. However, due to the extended duration and broad scope of the learning process, some students (33.3%) believe it adds to their academic workload.

Table 1 Questionnaire on the training effects of open laboratory---(n=60)[n(%)].

Evaluated Domains	**Yes**	**Neutral**	**No**
Are you satisfied with the content of open-ended experiments?	60(100)	0(0)	0(0)
Are you satisfied with the schedule of open-ended experiments?	60(100)	0(0)	0(0)
Did it help improve problem-solving skills?	47(78.3)	8(13.3)	5(8.3)
Did it contribute to the cultivation of clinical thinking?	50(83.3)	7(11.7)	3(5)
Did it contribute to the cultivation of innovative capabilities?	53(88.3)	4(6.7)	3(5)
Did it contribute to the cultivation of practical skills?	60(100)	0(0)	0(0)
Did it increase the learning workload and take up study time?	20(33.3)	13(21.7)	27(45)
Did it increase the proactiveness in learning theoretical knowledge?	45(75)	11(18.3)	4(6.7)
Did it reinforce the learning of clinical courses?	41(68.3)	9(15)	10(16.7)
Did it stimulate research interest?	60(100)	0(0)	0(0)
Were you satisfied with the team atmosphere you were involved in?	44(73.3)	10(16.7)	6(10)
Have you applied for a university-level student project?	60(100)	0(0)	0(0)
Did you receive funding for a university-level student project?	50(83.3)	0(0)	10(16.7)

Furthermore, feedback from students facing graduate school entrance exams and job interviews demonstrates that students who have undergone this training can effortlessly handle research and practical application-related questions during interviews. Some students have even managed to make a successful comeback in their graduate school entrance exams, with a success rate exceeding 98% in previous years.

4. Discussion

Experimental teaching is a crucial component of higher education. It serves as an essential means through which students can develop comprehensive skills such as problem discovery, understanding and analysis, logical reasoning, data handling, and report writing. Additionally, it plays a vital role in fostering students' practical and innovative capabilities [6]. The integration of research and experimental teaching in higher education, particularly the introduction of research-oriented experiments in undergraduate laboratory instruction to cultivate innovation spirit and enhance innovation capabilities, has become one of the central hot topics in establishing an innovative education system for medical students[7].

Based on the research-integrated innovative talent development model, with the goal of enabling students to 'enter the laboratory earlier, join projects faster, and become part of a team earlier on, ' and enhancing their original innovation spirit and research capabilities, we will be guided by the Undergraduate Basic Medical Innovation Forum and Experimental Design Competition. We will deepen the reform of experimental teaching, categorizing basic biochemical experiments into different types, including open experiments and comprehensive design experiments.

We have designed two levels for the open laboratory. The first level, the observation stage, aims to involve students as much as possible in experiment design and preparation work. This helps them gain a deeper understanding of the experimental principles, comprehend the objectives, and master the techniques. Importantly, during the observation and learning process, students develop a profound appreciation for the rules of using laboratory equipment and its routine maintenance. This significantly enhances their hands-on operational skills. The second level, the simple design stage, begins when students develop an interest. In this stage, the primary mode of learning is through PBL-style interactive classes. Each group initially proposes research directions that interest them and proceeds with a simple experiment design. This simple design experiment shifts the focus of experimental teaching to student-centered learning for the first time. It allows students to truly understand the relationship between ideas, implementation, outcomes, and transformation. This greatly ignites students' enthusiasm and interest in research. According to our survey results, all students are highly satisfied with the content and progress of open experiments. They believe that these experiments enhance their problem-solving abilities, contribute to the development of innovation and hands-on skills, and stimulate their interest in research. Moreover, 75% of the students feel that open experiments increase their proactive engagement in theoretical course studies and help solidify their understanding of the subjects. The implementation of open laboratories not only allows university students to master basic theoretical knowledge but also strengthens their practical skills. Ultimately, it aligns with the goal of 'integrating theory with practice.' For example, 68.3% of students feel that it reinforces their coursework, and 75% believe it enhances their proactive engagement in theoretical learning. Open experiments also provide students with access to research-oriented project experiment equipment and facilities, enabling them to engage with cutting-edge experimental techniques. As a result, 78.3% of students feel it contributes to improving their problem-solving abilities, and over 80% believe it helps nurture clinical thinking and innovation skills.

After undergoing training in the open laboratory and completing simple design experiments, students have acquired fundamental skills in biochemical experiments. This prepares them for the comprehensive design stage, where the experiments are primarily centered around research topics for university students. The selection of research topics in the comprehensive experiments is based on students' interests and strengths. These topics are chosen by members of the experimental groups and align with the research areas of the guiding professors. Proposals are prepared, and the student-led groups use the topics as materials for applying for research projects at our university. Survey results show that after the training in the open laboratory, all students actively applied for university-level research projects, with 83.3% of them receiving project funding. Once granted project funding, students can utilize the resources in the research laboratory to conduct their research, achieving a true 'learning through application' teaching effect. The implementation of comprehensive design experiments enables students to truly understand and master the fundamental processes of scientific research, laying a solid foundation for their future innovative scientific endeavors. Furthermore, the formation of student-initiated project interest groups not only cultivates their practical innovation capabilities but also fosters teamwork and enhances the strength of these teams. This enriches the learning atmosphere, improves interpersonal skills, and the survey indicates that 73.3% of students are highly satisfied with the team dynamics in which they are involved.

In summary, the efficient talent development model that combines teaching and research, with 'questions and topics as the core, students as the main body and competitions as the guide' can fully harness the proactive nature of medical students. It ignites their innovative thinking, enthusiasm for experimental exploration, and ultimately enhances their practical abilities.

References

[1] Rosenshine, B., Meister, C., & Chapman, S. (1996). Teaching students to generate questions: A review of the intervention studies. *Review of educational research*, 66 (02), 181-221.

[2] Lhoste. (2020). Can do-it-yourself laboratories open up the science, technology, and innovation research system to civil society? *Technological Forecasting & Social Change*, 161, 120-226.

[3] Huang, R., Liu, Z., Zi, D., Huang, Q., & Pan, S. (2022). A Multi-level Remedial Teaching Design Based on Cognitive Diagnostic Assessment: Taking the Electromagnetic Induction as an Example. *Frontiers in psychology*, 13, 851378.

[4] He H., Zhang H., Luo H. (2016). Design of multi-level teaching system based on association rule mining. *Int. J. Emerg. Technol. Learn.* 11, 43-48.

[5] Song, Liu, M.-Q., & Wu, S.-J. (2007). Engineering practice model and its application for multi-level open teaching. */ Experimental Technology and Management*, 24 (08), 93-95.

[6] Marli E. D. A. André, & Anderson, T. H. (1978). The Development and Evaluation of a Self-Questioning Study Technique. *Reading Research Quarterly*, 14 (04), 605-623.

[7] Shaw, Holbrook, A., & Bourke, S. (2013). Student experience of final-year undergraduate research projects: an exploration of “research preparedness.” *Studies in Higher Education (Dorchester-on-Thames)*, 38 (05), 711-727.