Application of Comprehensive and Design-oriented Experiments in Botany Teaching Based on Applied Talent Cultivation

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Abstract: In response to issues such as the singularity of traditional botany experiment teaching content, outdated methods, and subjective and one-sided assessment approaches, a comprehensive and design-oriented experimental teaching model and a more holistic assessment system were established based on the cultivation of applied talents. This approach integrates foundational experimental content, designs experimental plans, and specifies operational processes. This paper presents the current status and problems of botany laboratory teaching. Students lack the time and space for independent thinking. The teaching model cultivates students who lack innovation and creativity, and their hands-on ability is not exercised, which fails to meet the current society's for talents. The assessment method is monotonous. and the evaluation of experimental performance is not comprehensive, objective, and fair enough, mostly focusing on experimental operations and reports. This paper highlights the shortcomings of traditional teaching methods and analyzes the critical role of comprehensive and design-oriented experiments in enhancing students' practical abilities and fostering innovation awareness. It provides significant insights into improving the quality of botany experiment teaching and developing students' practical application skills, innovative thinking, and overall competence as applied talents.

Keywords: Botany Experiments; Comprehensive; Ability Training; Design-oriented; Practical Application Ability

1. Introduction

According to the spirit of the National Medium- and Long-Term Education Reform and Development Plan, Suzhou University has established a talent cultivation model characterized by "strong foundations," "practice-oriented learning," and "enhanced capabilities," tailored to its institutional and regional characteristics. Universities play a crucial role in fostering students' innovation awareness, creative thinking, and innovative abilities, with experimental teaching providing students with both activity and intellectual space [1]. Botany, as a core foundational course in the biological sciences, is also a discipline with a strong experimental focus. The objective of its experimental curriculum is not only to enable students to master fundamental experimental principles but also to enhance their practical application skills and learn to explore the mechanisms of plant life through experimental methods. These elements are indispensable in the cultivation of applied talents. Experimental teaching in universities is instrumental in developing students' scientific thinking, innovative capabilities, and exploratory skills [2-3]. Through experimentation, students can deepen their comprehension of theoretical concepts, enhance their hands-on skills, and stimulate innovative thinking. This aligns with the 21st-century goals of higher education, which emphasize creativity, innovation, and entrepreneurship as foundational features and aim to cultivate individuals with strong knowledge acquisition abilities, professional expertise, and research capabilities [4]. In recent years, to meet the evolving demands of society for talent, adjustments have been made to the professional curriculum structure. However, reductions in botany lecture hours and corresponding experimental class hours have resulted in a curriculum largely dominated by verification-based experiments. This approach provides limited exposure to cutting-edge scientific research and modern experimental techniques, falling short of fostering students' innovative thinking and hands-on abilities. To address these challenges, the botany experimental curriculum has been restructured into three major components: foundational, comprehensive, and design-oriented experiments. The focus is placed on cultivating students' scientific attitudes, critical thinking, innovative ideas, and problem-solving skills, while reinforcing foundational knowledge and operational competencies [5-6]. Consequently, reforming the teaching model is essential to engaging students more effectively and stimulating their intellectual engagement.

The traditional approach to botany experimental teaching is characterized by a narrow focus on isolated, verification-based experiments, lacking interconnection between experiments. This approach results in students forming fragmented and isolated understandings of problems, making it difficult for them to develop a comprehensive perspective on a given issue. Furthermore, it hinders the cultivation of deep thinking and proactive innovation. The teaching model remains traditional and instructor-centered. Before class, instructors prepare all necessary materials, reagents, and tools. They explain the objectives, principles, procedures, and precautions on the blackboard and then demonstrate the experimental process. Students merely replicate what the instructor has shown, following instructions step-by-step, and submit a report at the end of the session, marking the completion of the experiment. In this process, students remain entirely passive, with minimal opportunities for independent thinking or exploration. This limits their interest in learning and prevents them from systematically mastering experimental skills. Such a teaching model fails to foster creativity, innovation, and practical skills, making it inadequate for meeting the modern demands of society.

Assessment methods are similarly limited. The evaluation of experimental performance often relies heavily on the neatness of reports and the quality of drawings, with insufficient attention paid to the actual experimental operations or hands-on skills of students. In some cases, students photograph incomplete drawings during class to finish later or even replicate textbook illustrations, violating the principles of microscope-based observations and compromising the authenticity of their work.

In response to these challenges, this teaching team has developed a comprehensive, design-oriented experimental teaching model paired with a systematic and holistic assessment and evaluation method. This approach aims to address the shortcomings of traditional teaching and foster a more engaging and skill-oriented learning experience for students.

2. Implementation of Comprehensive and Design-oriented Experiments in Botany

China has entered a stage of mass higher education [7]. Within this context, traditional teaching models are being transformed to cultivate innovative talents. Modern teaching tools and resources, such as experimental instruments, digital microscopy systems, multimedia, and online platforms, have been introduced to enhance the educational experience. To ensure a more objective and equitable evaluation of students' experimental performance, a comprehensive assessment method has been adopted. This approach includes evaluating pre-class preparation, the rationality of experimental designs, the correctness of operational methods, the seriousness reflected in the experimental report, and adherence to laboratory hygiene standards. Reforming teaching models, adjusting teaching content, and igniting students' enthusiasm for learning have become essential. The introduction of comprehensive and design-oriented experiments is particularly crucial in fostering a learning environment that promotes innovation, practical skills, and active participation.

2.1 Replacing Verification-Based Experiments with Comprehensive and Design-oriented Experiments

Comprehensive and design-oriented experiments involve the instructor providing the objectives, requirements, and experimental conditions, while students take the lead in designing experimental plans, selecting methods and instruments, outlining procedures, conducting experiments, and analyzing results. Since students independently design the experiments, they must submit their plans for instructor review. This process, which often involves multiple rounds of revisions, is time-consuming for both instructors and students. However, it significantly nurtures students' independent thinking and in-depth inquiry skills. By integrating and deepening botany experimental content and adopting comprehensive, design-oriented experiments, students' scientific thinking, practical application, and innovative abilities can be effectively cultivated. For instance, in the study of plant tissues, students are grouped (e.g., four per group) and given broad beans, Petri dishes, and access to an incubator. Students germinate the seeds and grow seedlings. Once the seeds sprout and cotyledons develop, part of the material is used for hand-cut sections to observe various types of vascular tissues under a microscope, including annular, scalariform, spiral, pitted, and reticulate vessels. The remaining seedlings continue to grow, allowing for further experiments. As the cotyledons expand, leaves can be used to study protective tissues. Students strip the lower epidermis of a leaf, prepare a wet mount, and easily observe epidermal cells and guard cells under a microscope. Once the roots reach sufficient length, students use the material for hand-cut cross-sections to study the primary structure of roots. Staining the root sections with safranin enables clear observation of tetrarch xylem, a distinctive four-protoxylem structure. The size and arrangement of cells, including the tightly packed epidermal cells and the loosely arranged cortical cells with visible intercellular spaces, are evident. The fresh material also makes Casparian strips clearly visible. The alternating arrangement of primary phloem and primary xylem is distinct, offering better visual clarity than permanent slides. This approach not only improves students' understanding of plant anatomy but also enhances their hands-on skills, problem-solving abilities, and capacity for innovation through active engagement in the experimental process.

By cultivating broad bean seeds, multiple experimental topics are seamlessly connected, integrating the fragmented theoretical knowledge about cells, tissues, and organs into a cohesive framework. This approach enhances students' comprehension of structural concepts while simultaneously sparking their interest in experiments and developing their practical, cognitive, and problem-solving skills. For instance, the theoretical section on the primary structure of roots is often regarded by students as difficult to remember. However, through hands-on cultivation, slide preparation, structural observation, and comparison of differences, students achieve a deeper understanding of this content. This process not only hones their practical and independent thinking skills but also strengthens their ability to analyze and solve problems. More importantly, this method stimulates students' enthusiasm, initiative, and teamwork spirit, fostering collaboration among peers. It lays a solid foundation for subsequent coursework, ensuring a more engaged and effective learning experience.

2.2 Student-Centered, Teacher-Guided Teaching Model

Comprehensive and design-oriented experiments are conducted after students have acquired a certain level of theoretical knowledge and operational skills. The approach involves selecting appropriate experimental topics that integrate knowledge from multiple disciplines. Students independently design experiments, adjust interconnected conditions, observe the overall effects, and improve their scientific research, innovation, and independent experimentation abilities [8-9]. In this model, the teacher provides the experimental objectives, requirements, and conditions, while students take the lead in designing the experimental plan. They are responsible for collecting and processing materials and preparing necessary reagents. Toward the end of the semester, students, organized into groups, create a set of plant specimens, including permanent slides and wax leaf specimens, which will be used in future lessons. Permanent slides can be used to observe plant roots or seedling stems. Students grow plant seedlings in incubators and choose monocot plants like wheat, rice, and corn, or dicot plants like cotton, broad beans, soybeans, and sunflowers. Students independently design the operational procedures, including selecting the plant parts, determining the processing time, embedding, staining methods, slicing thickness, as well as the temperature and duration for drying slides. The entire process is carried out autonomously by the students. The creation of wax leaf specimens offers an opportunity for students to showcase their creativity. Some groups, with particularly well-crafted specimens, participated in the provincial university specimen competition and won first place. Not only were the specimens exquisitely made, but they also carried deep significance. In these experiments, the teacher's role is limited to offering guidance and inspiration. When students encounter problems, they engage in discussions with the teacher, but the students remain the primary drivers in solving and refining the experiment. The experiments are time-consuming, with most of the work completed during students' spare time. In addition to the mandatory tasks set by the teacher, students also explore areas of personal interest, such as preparing flower slides or pressing stem and root tips. The excitement captured through photos of the hands-on processes significantly boosts students' enthusiasm for the experimental sessions.

2.3 Increasing Practical Experience Through Laboratory Open Access

Connecting learned knowledge with production practices and scientific research fosters the development of application skills and innovative thinking, thereby cultivating high-level applied talents that serve local economic needs [10]. Firstly, students are encouraged to participate in practical activities, with the laboratory providing the necessary conditions for such engagement. For example, in the context of seed germination, students can use their spare time to explore the effects of various factors on seed germination, such as salt stress, heavy metal pollution, and plant hormones. With the available laboratory conditions, students can conduct these practical experiments using plant seeds like wheat, corn, and soybeans. The results of such experiments can offer valuable guidance for production practices, particularly as environmental pollution and soil contamination, especially heavy metal pollution, continue to worsen. While the course hours are limited, preventing in-depth experimentation on these topics within the formal curriculum, the open access to the laboratory allows students to conduct such experiments under the teacher's guidance outside of class, thereby providing an opportunity for further exploration and practical application of their knowledge.

3. Evaluation of Teaching Effectiveness

3.1 Improvement in Students' Research Abilities

The comprehensive and design-oriented experiments involve teachers providing a range of topics and directions, while students independently design the experiment, formulate the research plan, and implement it. Unlike traditional experiments with detailed guidance, students now rely on their existing knowledge and extensive reference materials to formulate meaningful research content and create feasible experimental plans. During the implementation, the teacher serves as a guide, offering inspiration and direction, but the students remain the primary researchers and executors of the experiment. Upon completion, it is observed that even when the experimental topics are the same, the materials and methods chosen by different students vary, and the experimental designs differ widely. Despite these differences, the results remain consistent. This demonstrates that students have mastered the necessary knowledge and are proficient in using the required instruments and equipment. Some experimental groups even used their topics to apply for university-level research projects, further deepening their research based on the initial experiments. This indicates that the experiments help students cultivate research thinking and foster innovation, providing a solid foundation for their future learning in other experimental courses. For example, in the fruit dissection experiment, using oil peaches, some students created fruit wine and participated in the university's fruit wine competition, winning second place at the university level. They also applied for a university-level innovation and entrepreneurship project titled "The Effect of Selenium-enriched Yeast on the Quality of Oil Peach Fruit Wine" (Project Number: KYLXYBXM22-245).

3.2 Cultivation of Students' Comprehensive Analytical Skills

Each comprehensive and design-oriented experiment requires students to consult numerous reference materials, develop a research plan, conduct the experiment, analyze and organize data, create PowerPoint presentations, and sometimes even write a small research paper. All of these tasks are completed independently by the students. While some experimental plans may be theoretically sound, practical execution often encounters unexpected challenges. For example, in the process of preparing leaf cross-section permanent slides, the leaf must be properly aligned during wax embedding to ensure it remains flat. This requires precise control over the speed and volume of the molten wax to maintain uniformity; otherwise, the leaf will not lie on the same plane, requiring repeated practice and patience. During the slicing process, wax sections often break, preventing the formation of a complete cross-section. This forces students to investigate the issue, consult additional resources, and find solutions. In the process of overcoming these obstacles, students not only hone their practical skills, independent thinking, and teamwork, but also develop resilience, determination to overcome setbacks, and an enhanced ability to handle failure. These experiences strengthen their ability to persevere and solve problems, fostering both technical and psychological growth.

3.3 Areas for Further Improvement

Although the difficulty of the botany experiments themselves is not high, the cultivation of materials can be time-consuming and labor-intensive. For example, the cultivation of materials such as young roots, young stems, and seedling plants requires significant effort. To improve efficiency, it could be considered that one person from each group be assigned to prepare and cultivate these materials collectively, with the materials then provided uniformly to the other groups. This would save time and ensure a more streamlined process, allowing for more focused work during the experiment.

In terms of arranging experimental content, it would be beneficial to schedule different tasks separately to avoid conflicts in the use of equipment. Additionally, the timing of the experiments should not be confined to class hours; extending the laboratory's open hours would allow students to complete their experiments continuously without interruptions. Regarding grading, the current system for evaluating performance in experimental groups (with 4 members per group) lacks sufficient differentiation, resulting in minimal variation in the grades among group members. It would be helpful to develop a more detailed and quantifiable evaluation method that more accurately reflects each student's individual contribution and performance.

4. Establishing a More Comprehensive Grading Mechanism

To reform the grading system for botany experiments, the evaluation should encompass five aspects: the design of the comprehensive design-oriented experiment, the experimental process, the analysis of results, the writing of the experiment report, and oral testing. The weight distribution could be as follows: 65% for experimental design and operation, 25% for the experiment report, and 10% for the oral test. This approach fundamentally encourages students to focus on experimental design and hands-on application, stimulating their innovative thinking and practical skills. The experiment report should no longer follow traditional methods where the teacher writes on the board for students to copy; instead, students should write reports based on their own experimental plans and procedures. Reports could also be submitted in the form of a small research paper. For the oral test, the teacher will design questions based on the semester's experiment content, with students answering on the spot. The questions can be flexible, ranging from specific experimental procedures to the preparation methods of certain reagents. This more dynamic approach will better assess students' understanding and engagement with the material.

5. Conclusion

The implementation of comprehensive, design-oriented experiments has successfully fostered students' innovation awareness, creative abilities, and scientific literacy. These experiments not only evaluated students' proficiency in basic validation experiments but also highlighted their overall capabilities. By integrating the knowledge they acquired, students have enhanced their practical skills and deepened their understanding of theoretical concepts. In the future, we will continue to explore and improve the various aspects of design-oriented experiment teaching in botany, with an emphasis on further developing students' independent thinking and innovative problem-solving abilities.

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