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Innovation Experimental Teaching Design: Integrating Profound Significance with Competency Development*

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Abstract

Focusing on the characteristics of innovative experimental teaching, this paper employs multiple evaluation methods to analyze the functions of the experimental system in detail, emphasizing the cultivation of students' moral character, as well as enhancing their experimental skills and scientific research competence. The course uses cutting-edge research as a vehicle, integrating knowledge from inorganic chemistry, analytical chemistry, biology, and physical chemistry to construct a full-chain scientific research process: "literature review - scheme design - solution-phase synthesis - multidimensional characterization - biological evaluation - data mining - manuscript writing." Teaching is implemented in groups of 2–3 students, with teachers acting as guides to intervene in safety monitoring, experimental optimization, and data analysis. Students significantly enhance their innovative thinking, practical ability, teamwork skills and sense of social responsibility through independent design, standardized operations, statistical testing, and results presentation, providing a replicable model for cultivating top innovative talents.

Keywords

Innovation experiments; Talent cultivation; Profound significance.

1. Introduction

The integration of science and education aims to break the boundaries between research and teaching, achieving the co-creation, sharing, and transmission of knowledge. On one hand, incorporating mature and outstanding scientific ideas, methods, and achievements into teaching enriches the curriculum, exposes students to the latest scientific knowledge, enhances their practical understanding, broadens their horizons, and stimulates their enthusiasm and interest in scientific research. On the other hand, teaching activities provide research with talent and intellectual support, cultivate students' research abilities, and inject new vitality into scientific research [1].

To enhance students' technological innovation capabilities, the applied chemistry major of our school has launched an innovative experimental course for students. This course adopts a design that integrates science and education, aiming to cultivate students' innovative consciousness, deepen their understanding of interdisciplinary knowledge, improve their practical skills, and at the same time foster teamwork, inquiry-based learning, problem-solving abilities, broaden their academic horizons, stimulate their interests, and cultivate scientific attitudes and spirits.

The innovative experiment integrates the theoretical and experimental knowledge of inorganic chemistry, analytical chemistry, biochemistry, and physical chemistry, closely following the cutting-edge research in antibacterial materials. It covers the research of material synthesis, structure analysis, biological activity evaluation, data analysis and improvement strategies,

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achieving the integration and synergy of knowledge, and providing a platform for students to enhance their academic and comprehensive qualities. It enables students to apply the theoretical knowledge learned in class to solve complex real-world problems, thereby deepening their understanding in practice and promoting the internalization and transfer of knowledge. During the experiment, students need to determine the plan through literature research, design and synthesize functional materials by applying theoretical knowledge, and transform theory into practice. Through operation and practice, students can convert abstract chemical concepts into specific solutions, significantly enhancing their practical and innovative abilities [2].

In teaching, the teacher acts as a guide, assisting students in literature collection, experimental planning, monitoring execution, and data analysis [3]. The teacher also guides students to review and improve experiments, fostering independent and innovative thinking. This teaching model enables students to deeply master the knowledge of synthesis, characterization, and application of functional materials; enhance their innovative thinking, analytical reasoning, and comprehensive academic application abilities; and lay a solid foundation for future research and paper writing.

2. Teaching Design

2.1. The Exploration of Profound Significance Elements

Education has always adhered to excellent traditions, emphasizing that "moral cultivation" is the foundation of "educating people, " and is committed to imparting knowledge and skills while also focusing on the cultivation of morality, achieving an organic integration of moral education and talent development. In terms of establishing one's character, conducting studies, and delivering education, it has always adhered to the principle of basing it on morality, strengthening the cultivation of students' outlook on life, worldview, and values, thereby cultivating more individuals with both moral integrity and talent.

According to the requirements of higher education, the experimental teaching sets two educational goals: first, to cultivate students to form correct values so that they are willing to devote themselves to the construction of society; second, to master professional theoretical knowledge and cultivate students' ability to solve practical problems. In the integrated teaching practice of science and education, according to the teaching content, the profound significance elements are deeply explored, thereby forming a teaching model that closely combines value orientation and knowledge transmission and is mutually reinforcing. The experimental teaching content includes material preparation, characterization testing, performance testing, etc. Table 1 lists the profound significance elements extracted from five experimental teaching cases.

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Table 1. Integration of elements of teaching and moral education

Relevant Knowledge	Deeply Significant Elements	Case Analysis
Preparation of Graphene Oxide	Be realistic and adhere to the truth	In 1958, Professors Hummers and Offeman obtained graphene oxide (GO) through an oxidation reaction experiment.
The application of copper	Attach importance to the fundamentals and promote interdisciplinary studies	Thousands of years ago, the ancient Egyptians had already used copper for disinfecting wounds and purifying drinking water.
The application of copper	Be courageous in practice and bold in innovation	In the Ming Dynasty, Li Shizhen recorded the medicinal value of copper rust on copper coins in his work "Compendium of Materia Medica".
The properties of graphene oxide and its applications in real life	Educational and scientific development to invigorate the country, dedication to society	Graphene oxide has been processed into antibacterial masks, protective suits and other products, providing a guarantee for people's life safety.
The application of copper	Break through conventions, set a new precedent	In contemporary times, copper nanoparticles can be utilized to enhance the antibacterial properties of dental implants and fillings.

Case 1: In 1958, Professors Hummers and Offeman conducted meticulous observations and recorded the findings, promptly identifying the problems in the experiments and making corresponding adjustments and optimizations. Eventually, through the oxidation reaction experiments, they successfully prepared graphene oxide (GO). These details prompted the students to reflect and enabled them to understand the scientific attitude of scientists, which is characterized by being realistic and rigorous.

Case 2: Thousands of years ago, the ancient Egyptians discovered by chance that drinking directly from wells and rivers could easily cause diarrhea, but drinking water that had been stored in copper containers for a period of time could avoid this problem. This was a simple manifestation of people's life experience. Later, they gently sprinkled the same copper water onto a cut wound and were astonished to see the redness and swelling gradually fading and the pus decreasing. Thus, copperware became the earliest "antibiotic kit." This case emphasizes the integration of interdisciplinary knowledge and encourages students to learn knowledge from related fields such as chemistry, biology, history, and sociology. They should analyze the "copper water" phenomenon from different perspectives and learn to apply multidisciplinary knowledge to solve new problems in modern antibacterial materials and public health.

Case 3: During the Ming Dynasty, Li Shizhen carried his medicine box, wore sandals made of green leather, and ventured into fields, fishing ports, and mines. He engaged in deep conversations with herbal collectors, woodcutters, blacksmiths, and fishermen, jotting down their individual experiences in the accompanying booklet. Once, he heard that "green rust from copper mirrors can speed up the drying of sores." So, he personally collected copper rust and first tasted it with his tongue to determine its flavor, then applied it to his own eczema with a mixture of water, repeatedly testing the dosage and compatibility to confirm that it could relieve scarring, remove decay, heal wounds, and kill insects. Eventually, he carefully included it in the "Compendium of Materia Medica." This case enables students to understand Li Shizhen's spirit of courageous practice and bold innovation, thereby inspiring students to cultivate their own innovation abilities.

Case 4： Scientific researchers used new materials such as graphene oxide to carry out work and successfully developed masks and protective suits with antibacterial functions. This provided protection for the lives and safety of the general public and medical staff. This case

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made students understand the significance of technological integration and thus fostered the awareness of contributing to society.

Case 5: In the past, we extensively relied on antibiotics to impart antibacterial properties to dental implants and fillings; however, this widespread use inevitably led to the emergence of bacterial resistance, which in turn greatly diminished the therapeutic efficacy of these drugs. Today, we have shifted to copper nanoparticles to enhance the antimicrobial performance of implants and restorative materials. Copper exhibits potent, broad-spectrum antibacterial activity, excellent biocompatibility, and crucially a very low propensity to induce resistance in bacteria. This case vividly demonstrates to students how scientists, confronted with therapeutic setbacks, summon the courage to innovate, explore new material solutions, and persistently tackle formidable challenges.

2.2. Experimental Teaching Practice

In the practice of experimental teaching, students should be specifically arranged to participate in experimental activities, which can stimulate their learning interest and deepen their understanding of theoretical knowledge. Thus, the learned knowledge can be applied to the comprehensive development of students. Through three stages: pre-class guidance, in-class practice, and post-class feedback-experimental teaching activities are designed to explore a new model of experimental teaching under the concept of integrating science and education. The specific arrangement based on the case of the antibacterial experiment of materials is shown in Table 2 It is expected that through this case, students with profound theoretical knowledge and rich practical experience in applied chemistry can be cultivated.

Table 2. Display of the Corresponding Relationship Between the Stages of the Experimental Project and the Application of Knowledge, Skill Enhancement

Experimental	Literature	Plan Design	Experimental Content				
			Preparation of Particles	Characterization	Performance	Data Analysis	Paper Writing
Results	A Review on the Preparation Methods of Oxidized Graphene/Cu_2O Composite Particles	Design an experimental plan	Preparation of graphene oxide/Cu_2O composite particles by liquid-phase synthesis method	The Zeta potential of the sample was determined using a laser particle size analyzer. The microscopic morphology of the sample was observed using a transmission electron microscope. The correct synthesis of the product was confirmed by means of a Fourier-transform infrared spectroscopy.	By employing techniques such as particle size analysis, transmission electron microscopy observation, infrared spectroscopy, potential measurement, and photothermal detection, the performance of the particles was comprehensively evaluated.	Analyze and summarize the above characteristics in conjunction with the test data.	Formulate an experimental report or a thesis project.
Theoretical	Literature search and summary of key points	Scientifically and reasonably design the experiment	The principle and operation of liquid-phase synthesis	The principles of common characterization methods.		Data analysis	Summary and analysis of data patterns
literacy	Literature research and reading	Independent learning and innovation ability	Liquid-phase synthesis training and experimental skills training	Operation and usage of common instruments and equipment		Use of Excel and Common Software	Writing of Scientific Papers
Summary and Outlook	Based on the results of literature research, experimental operations and data analysis, a predictive summary and outlook are provided for the future development path of graphene oxide/Cu_2O composite particles, in order to cultivate innovative thinking and forward-looking thinking, identify potential problems, and propose targeted solutions to address these issues.						

2.3. Experimental Procedure --- Taking the Antibacterial Experiment of Materials as An Example

(1) Experimental Design and Planning: The teacher should first explain to the students the importance of antibacterial materials in daily life and clearly define the specific goals of the experiment. Then, the teacher guides the students to conduct a thorough literature review and collect and study the latest progress and key theories in the field of antibacterial materials. Through the teacher's explanation, the students will deeply understand the antibacterial mechanism of the materials, the preparation technology, and the performance evaluation criteria (Table 3), thereby encouraging the students to propose innovative experimental ideas based on the literature and personal insights. Subsequently, the teacher should host a group discussion, allowing the students to present their experimental ideas and assisting them in

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optimizing the experimental design through peer and teacher feedback, ensuring the feasibility and innovativeness of the ideas.

(2) Experimental Preparation and Implementation: The teacher provides the students with necessary experimental reagents and equipment, outlines the basic knowledge of antibacterial materials, their classification, and practical applications, and explains the experimental steps and details to be noted. Then, the students are divided into several groups of 2 to 3 people, and they are organized to conduct pre-experiment drills under the teacher's guidance. Under the teacher's supervision, the students simulate the preparation process of antibacterial materials and master the operation methods of laboratory synthesis equipment. The teacher guides the students to perform standardized operations, carefully observe the experimental phenomena, and accurately record the data. At the same time, necessary guidance and feedback are provided.

(3) Data Analysis and Results Processing: Teachers must strictly follow laboratory data-management regulations, supervise students' submission of raw readings, intermediate calculation sheets, and final summaries in the prescribed format, and verify completeness, accuracy, and unit consistency. They then demonstrate how to rearrange these records into a clear, column-and-row structure that is easy to read and ready for analysis. Afterward, instructors provide hands-on guidance on selecting appropriate graphing tools to create line, bar, or box plots and standardizing axes, error bars, and legends, while simultaneously helping students draft formal reports that include purpose, methods, results, and discussion, thereby laying a solid foundation for deeper interpretation. Finally, teachers lead descriptive statistical tests or ANOVA to evaluate the significance of experimental outcomes, offering one-to-one feedback tailored to each student's progress and weaknesses to achieve truly personalized improvement.

(4) Conclusion and Evaluation: The instructor conducts a meticulous, multi-layered analysis of each student's raw data, employing cross-validation, error-tracing, and significance re-testing to guarantee its accuracy, integrity, and reliability. These verified results are then benchmarked against real-world clinical, environmental, or industrial scenarios-calculating antimicrobial efficacy, cost–benefit ratios, and scale-up feasibility-to appraise their potential practical value. Simultaneously, the teacher examines the problem-solving trajectory demonstrated by students during hypothesis framing, protocol design, failure diagnosis, and collaborative decision-making, mapping their performance quantitatively against predefined competency rubrics to evaluate the overall pedagogical impact of the experiment. Furthermore, students who exhibit sustained enthusiasm are recruited into a rolling incubation pipeline: they receive privileged access to major instrumentation, seed funding, and external mentorship; are guided to transform experimental outcomes into grant proposals, SCI publications, and patent applications; and are coached to assemble multidisciplinary teams for high-profile innovation and entrepreneurship contests such as "Internet-Plus" and "Challenge Cup." Through business-plan writing, pitch-deck refinement, and venture-capital roadshows, their creative thinking, logical analysis, and market insight are systematically sharpened, forging a seamless "classroom-lab-competition-industry" talent-cultivation chain that continuously energizes technological innovation and societal progress.

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Table 3. Characterization methods and purpose of experiments

Characterization methods	Table Objectives	Remarks
Zeta potential measurement	Measure its surface potential	Must do
Transmission electron microscope (TEM)	Analyze the structure and morphology of the sample	Must do
Fourier-transform infrared spectroscopy (FT-IR)	Confirm the successful preparation of the sample and the completion of the synthesis process	Must do
Bacterial plate experiment	Evaluate the inhibitory ability of particles on bacterial growth	Must do

3. Experimental Section

To ensure the smooth progress of the experiment, the following key points need to be paid attention to during the teaching process:

(1) Emphasize the safety of experiments: The safety of experiments plays a decisive role in ensuring the smooth progress of the experimental process and the life safety of the experimenters. Considering that the unique physical and chemical properties of materials may pose potential risks to human health and the environment, strict safety regulations must be followed when conducting related experiments to ensure their safety. Before entering the laboratory, teachers and students must complete online safety training and access assessment, familiarizing themselves with the toxicity levels of chemicals, the explosion limits of metal dust, and the exposure pathways of nanomaterials. During the experiment, they must wear standard-compliant goggles, double-layer gloves, and puncture-resistant lab coats and precisely control temperature, humidity, and airflow in the fume hood to ensure that the concentration of harmful gases and dust is below the occupational exposure limit. At the same time, a "double-person supervision" mechanism should be established, with one person operating and the other person checking. All hazardous waste should be classified, labeled, and weighed and then handed over to professional institutions for disposal, ensuring that the entire process from entry to exit is risk-controllable and building a safety barrier for life and health to facilitate the smooth progress of teaching and research.

(2) The experimental content is rich and varied; therefore, a student-centered small-group approach is adopted to maximize the utilization of laboratory time and equipment. Before the experiment, the instructor must carefully guide students to master instrument operation, calibration, and maintenance safety rules; systematically explain the antibacterial principles of the materials; and detail the entire workflow—medium preparation, inoculation, incubation, and data recording—while demonstrating aseptic techniques and highlighting common pitfalls. Students are then led to discuss variables and controls within their teams and are coached to finalize an experimental plan that includes timelines and contingency procedures, ensuring a smooth and efficient implementation. After the experiment, each group is responsible for data analysis, report writing, and experimental summary, thereby completing a full cycle of scientific training.

(3) Teachers need to supervise and guide students in formulating experimental plans before the experiment, which should include experimental steps, required materials, and expected results. For instance, the operational steps of the bacterial culture experiment should be clearly defined. Students need to record the inoculation volume, culture temperature, start and end times, colony morphology, color, size, and optical density changes in real time and take photos for archiving to prevent information loss and ensure the completeness and traceability of the data, providing a reliable basis for subsequent analysis. In addition, appropriate data analysis methods should be adopted to ensure the accuracy of the analysis results.

4. Conclusion

This experimental course keeps pace with the latest advances in both scientific research and pedagogical innovation. By integrating cutting-edge technologies, we have constructed a comprehensive, multi-level, and scalable laboratory-teaching ecosystem specifically designed to cultivate students' innovation capacity, critical-thinking habits, and advanced practical skills. To further enhance interactivity, intellectual depth, and learning impact, the course model is undergoing continuous optimization through a series of strategic upgrades: (i) embedding open-ended micro-research projects that originate from real-world, grant-funded investigations; (ii) coupling physical wet-lab work with high-fidelity virtual-simulation modules that allow predictive experimentation and failure-free rehearsal; (iii) fostering cross-disciplinary collaboration among departments of chemistry, microbiology, pharmaceutical science, materials engineering, data science, and industrial design so that learners can experience the entire innovation chain-from molecular design and algorithmic screening to prototype fabrication and market evaluation; and (iv) implementing a dynamic, evidence-based assessment matrix that combines real-time electronic-lab-notebook analytics, peer review, instructor coaching, and industrial mentor scoring. Thanks to its strong integrative nature, the program has already produced measurable gains in student creativity, research productivity, and entrepreneurial readiness, thereby offering fresh perspectives and replicable paradigms for higher-education reform. Continual refinement of this model is expected to accelerate the cultivation of elite professionals equipped with frontier-crossing innovation capabilities and the leadership qualities required to meet future technological and societal challenges.

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