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Exploration of Cultivation Models for Chemistry-Related Science and Technology Competitions under the Background of New Quality Productive Forces

Qingqing Lu, Furui Ma, Libin Liu*

School of Chemistry and Chemical Engineering, Qilu University of Technology (Shandong Academy of Sciences), Jinan, 250353, China
**Corresponding author*

Abstract: *Against the backdrop of the accelerated development of new quality productive forces, chemistry, as a fundamental discipline and a key area intersecting with emerging technologies, faces new challenges in talent cultivation. This paper focuses on chemistry-related science and technology competitions for university students, analyzing the core requirements of new quality productive forces for chemistry talents and examining existing issues in current competition cultivation models, including competition systems, industry-education integration, faculty development, and incentive mechanisms. By incorporating practical cases in green chemistry and new material development, this study proposes optimization strategies such as constructing competition systems aligned with the demands of new quality productive forces, deepening industry-education integration in chemistry, strengthening faculty development in chemistry disciplines, and improving incentive mechanisms for chemistry competitions. The aim is to enhance the educational effectiveness of chemistry-related competitions and provide pathway references for cultivating innovative chemistry talents in universities that meet the needs of new quality productive forces.*

Keywords: *New Quality Productive Forces, Chemistry-Related Science and Technology Competitions, Cultivation Model, Industry-Education Integration, Innovation Capability*

1. Introduction

New quality productive forces (NQPF), driven primarily by scientific and technological innovation, emphasize achieving qualitative leaps in productivity through interdisciplinary integration, technological breakthroughs, and industrial upgrading[1]. As a central science, chemistry maintains strong interdisciplinary connections with energy, materials, environmental science, pharmaceuticals, and other critical fields, serving as a fundamental disciplinary pillar for developing NQPF. University-level chemistry competitions (e.g., the National Undergraduate Chemistry Experiment Innovation Design Competition and the "Challenge Cup" National Academic Science and Technology Competition) represent vital platforms for cultivating top-tier chemistry talents. However, traditional competition models suffer from outdated content and disconnects between academia and industry, failing to meet NQPF's demands for innovative chemistry professionals. Developing NQPF-adapted cultivation models through these competitions holds significant implications for enhancing chemistry education quality, advancing disciplinary development, and facilitating NQPF realization.

2. Core Competency Requirements for Chemistry Talents Under NQPF

2.1 Interdisciplinary Innovation Thinking and Cross-Disciplinary Research Capabilities

The NQPF context increasingly requires multidisciplinary knowledge integration (biology, materials, environment, computer science, etc.) to solve complex chemistry problems[2]. For instance, developing novel solid-state battery electrolytes demands inorganic chemistry expertise for material synthesis/optimization, polymer physics understanding for electrical properties, and engineering knowledge for scalable production. Chemistry professionals must transcend disciplinary silos to develop multidimensional problem-solving capabilities.

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2.2 Industry-Oriented Innovation and Practical Competencies

Chemistry professionals must develop acute foresight to stay abreast of cutting-edge research and technological advancements. Chemistry-related science competitions should align closely with industrial upgrading demands, cultivating students' ability to translate laboratory discoveries into practical applications. For instance, in response to the new energy industry's demand for high-energy-density batteries, students are guided to conduct comprehensive research on novel electrode materials encompassing the entire workflow from synthesis and characterization to performance evaluation. Through strategic collaboration with industry partners to optimize pilot-scale production processes, this approach significantly compresses the timeline from scientific discovery to technological implementation.

2.3 Team Collaboration and Problem-Solving Skills

NQPF projects necessitate unprecedented collaboration beyond traditional disciplinary boundaries, requiring effective coordination among materials scientists, engineers, computer specialists, etc. For example, developing advanced battery materials concurrently requires addressing reaction mechanism optimization, mass-production process scaling, and carbon footprint assessment. This paradigm shift demands dismantling disciplinary "Towers of Babel" to construct "Chemistry+X" collaborative networks that generate synergistic effects (1+1>2), transforming linear thinking into multidimensional strategy formulation to bridge lab-scale innovations and industrial value creation efficiently.

3. Existing Problems in Current Cultivation Models for Chemistry-related Science and Technology Competitions

3.1 Disconnection between Competition Content and NQPF Requirements

The themes and content of chemistry-related science competitions often lag behind contemporary advancements. Many competitions still emphasize fundamental chemical experimental skills (e.g., titration analysis, routine organic synthesis operations), while few focus on emerging fields like green chemistry or the integration of chemistry with artificial intelligence. This makes it difficult to guide students toward exploring chemistry research directions related to new quality productive forces. Furthermore, the competition hierarchy remains underdeveloped. University-level chemistry competitions suffer from low participation rates and monotonous organizational formats, lacking appeal. At the provincial and national levels, selection criteria are not sufficiently scientific, overemphasizing theoretical performance while neglecting students' innovative thinking and practical abilities. As a result, many promising students and teams fail to stand out, limiting the role of chemistry competitions in cultivating talent for NQPF.

3.2 Superficial Industry-Education Integration with Low Enterprise Engagement

The current cultivation model for chemistry-related science competitions exhibits a notable superficiality in industry-education integration, primarily manifested through low corporate engagement and limited collaboration formats that fail to genuinely address industrial needs. Most competitions remain confined to university-proposed topics, with enterprises participating merely as sponsors or judges, lacking deep collaborative mechanisms. For instance, while the China International College Students' Innovation Competition includes corporate-proposed challenges, there exists a 30% mismatch between technical requirements and actual research frontiers, rendering most entries non-viable for practical application. Feedback from a chemical company revealed that although student-designed "novel coating formulations" demonstrated innovation, they overlooked critical industrialization factors like cost control and process compatibility, resulting in below 10% conversion rates. This shallow integration not only constrains students' ability to solve real-world industrial problems but also diminishes the competitions' role in driving industrial upgrading.

3.3 Weak Faculty Development in Chemistry Disciplines

Among chemistry competition instructors, some lack hands-on industrial experience and cutting-edge research exposure, resulting in insufficient understanding of the latest industry developments and practical demands. When mentoring students in chemistry competitions, they often struggle to provide

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forward-looking and practical guidance. For instance, in advising students on novel chemical catalyst development projects, these instructors cannot adequately address critical technical requirements or improvement directions from real-world applications. Furthermore, the teacher training system lags behind current needs, with most programs still focusing on fundamental teaching skills while lacking specialized training for scientific competitions. Additionally, the evaluation system disproportionately emphasizes paper publications and classroom teaching, failing to recognize competition mentoring achievements. This oversight diminishes instructors' motivation to engage in competition cultivation.

3.4 Excessive Outcome-Orientation with Insufficient Process Cultivation

The current cultivation model for chemistry-related science competitions exhibits a marked "emphasis on outcomes over process" tendency, where evaluation systems disproportionately focus on explicit indicators such as award rankings while neglecting the long-term development of students' innovative capacities. This is concretely reflected in the prevalent adoption of "one-time final" summative assessments in most competitions, which fail to incorporate process-oriented evaluations of critical stages including topic selection rationale, experimental design, and data processing, thus leading students to prioritize short-term achievements at the expense of proper research protocol training. A 2023 National Undergraduate Chemistry Experiment Competition survey revealed that approximately 65% of participating teams engaged in "last-minute cramming," concentrating solely on perfecting experimental outcomes while systematically weakening the cultivation of scientific thinking. Furthermore, higher education institutions generally lack tiered training mechanisms in competition cultivation, typically concentrating resources on "elite students" with immediate award potential rather than establishing comprehensive cultivation systems that encompass lower-grade students. This outcome-driven approach not only fragments research training but also exacerbates the Matthew Effect in the allocation of educational resources.

4. Optimization Strategies for Chemistry Competition Cultivation Models Under NQPF

4.1 Constructing "Frontier-Oriented + Interdisciplinary" Competition Content Systems

The current chemistry competition system should be fundamentally restructured to align with the demands of NQPF, with competition themes and content redesigned to emphasize cutting-edge chemical frontiers and interdisciplinary integration. This requires establishing innovative competition categories such as "Chemistry + New Energy," "Chemistry + Biomanufacturing," and "Chemistry + Artificial Intelligence" cross-disciplinary tracks. For instance, the National Undergraduate Chemistry Experiment Competition could introduce a "CO_2 Electrocatalytic Reduction for Fuel Production" segment, challenging students to integrate knowledge of electrochemistry, catalytic chemistry, and materials characterization to design highly efficient, low-energy consumption reaction systems. Additionally, competition projects are encouraged to integrate emerging technologies such as big data analytics and 3D printing. For instance, in chemical engineering contests, students may be required to leverage big data to optimize chemical processes and employ 3D printing technology to fabricate microreactors. Through the intersection and convergence of interdisciplinary knowledge, this approach cultivates students' comprehensive problem-solving skills. Simultaneously, the hierarchical structure of chemistry competitions needs optimization through strengthened organization and management of university-level events, with diversified formats including chemical innovation experiment design contests and science communication competitions to enhance student engagement. At provincial and national levels, selection mechanisms should be reformed to implement multidimensional evaluation criteria that comprehensively assess theoretical knowledge, innovative thinking, practical skills, and teamwork capabilities, thereby providing exceptional students and teams with expanded platforms for showcasing their talents.

4.2 Establishing "University-Enterprise-Research Institute" Collaborative Platforms

In terms of resource sharing and integration, the three parties leverage their unique strengths to achieve complementary advantages. Universities possess abundant theoretical teaching resources and a solid research foundation, offering open access to laboratories, shared research data, and literature resources, thereby providing students with an excellent environment for theoretical learning and fundamental research. Enterprises, on the other hand, provide real-world production scenarios and industrial experience, offering pilot workshops, production equipment, and technical challenges encountered in actual production, enabling students to understand real industry needs. Research institutes

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possess cutting-edge technologies and innovative achievements, sharing the latest research results and technical materials. By establishing a resource-sharing platform, the three parties create an online database for sharing research outcomes and experimental data, while also opening up physical facilities such as laboratories and production workshops offline, breaking down resource barriers and providing comprehensive support for chemistry-related technology competitions. In addition, a regular communication mechanism must be established, with the three parties holding joint meetings periodically to discuss project directions for chemistry-related technology competitions, talent cultivation, and other matters. Unified management standards are formulated to clarify the rights and obligations of each party in competition organization, student training, and result commercialization. For example, universities are responsible for theoretical teaching and fundamental research guidance, enterprises provide practical training sites and technical requirements, and research institutes offer cutting-edge technical guidance to ensure orderly collaboration. A joint incentive mechanism is implemented to reward outstanding students, mentors, and actively participating enterprises and research institutes in competitions. For instance, the "Chemical Innovation Collaborative Education Award" could be established, providing financial support to outstanding project teams and granting titles such as "Model Collaboration Unit" to enterprises and research institutes that make significant contributions, thereby boosting participation enthusiasm. Joint training and academic exchange activities are organized, inviting university professors, corporate engineers, and research institute experts to deliver lectures and share theoretical knowledge, practical experience, and the latest advancements, broadening students' horizons. A dual- or multi-mentor system can be introduced, assigning academic mentors from universities, practical mentors from enterprises, and technical mentors from research institutes to guide participating students from different perspectives[3]. For example, in a chemical sensor development competition, university mentors guide students in fundamental theoretical research, corporate mentors assist in optimizing sensor stability and practicality, and research institute mentors provide recommendations on new material applications, helping students enhance their innovation capabilities and comprehensive competencies.

4.3 Strengthening Chemistry Faculty Development

Universities and competition organizing institutions should regularly conduct teacher training programs, focusing on cutting-edge technologies in the field of chemistry and competition guidance methodologies. For instance, specialized training sessions such as "Applications of Artificial Intelligence in Chemical Research" and "Green Chemistry and Sustainable Development" can be offered to help teachers master new technologies and tools. Meanwhile, faculty members should be encouraged to participate in high-level academic conferences and industry forums, both domestically and internationally, to broaden their horizons and stay updated on the latest research trends and industrial demands. Additionally, a "mentor database" can be established by inviting industry experts, corporate engineers, and researchers from scientific institutions to serve as part-time instructors, providing students with diversified technical support and practical guidance. Universities should actively collaborate with chemical enterprises, environmental agencies, and high-tech companies to establish joint laboratories or practical training bases, offering faculty opportunities for professional secondments and participation in industry-academia-research projects. Through hands-on project experience, teachers can more accurately identify industry pain points, thereby guiding students to conduct research with greater practical value in competitions. For example, teachers can collaborate with enterprises to develop competition topics such as "Efficient Catalytic Degradation of Industrial Wastewater" or "Design and Synthesis of Novel Battery Materials," ensuring that competition entries directly address industrial needs. Breakthrough achievements in chemistry-related competitions often stem from interdisciplinary collaboration. Universities should break down disciplinary barriers by forming guidance teams composed of faculty from chemistry, physics, biology, computer science, and other relevant fields, enhancing the innovation of competition projects through collaborative efforts. For instance, in a "Chemical Molecular Simulation and Design" competition, chemistry teachers can work alongside computer science instructors to guide students in using machine learning algorithms to predict molecular properties, thereby elevating the technical sophistication of the project. Furthermore, an interdisciplinary competition guidance committee can be established to hold regular seminars, fostering communication and resource-sharing among teachers from different disciplines. Universities should incorporate competition guidance into the faculty performance evaluation system, offering outstanding instructors promotions, research funding incentives, or monetary rewards. For example, Qilu University of Technology (Shandong Academy of Sciences) explicitly includes competition guidance achievements in faculty promotion and performance assessment criteria, significantly boosting teachers' enthusiasm and initiative in mentoring chemistry competitions. Additionally, titles such as "Outstanding Competition Mentor" can be introduced to enhance faculty members' sense of honor and responsibility. Moreover, teachers should be encouraged to integrate

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competition guidance with research projects, such as transforming students' competition outcomes into academic papers or patent applications, achieving a win-win scenario for both teaching and research. Through collaboration with internationally renowned universities and competition organizations (e.g., the International Chemistry Olympiad (IChO) and the American Chemical Society (ACS) competitions), faculty members can be selected for overseas training to learn advanced competition coaching models. Simultaneously, international experts can be invited to deliver lectures or workshops on campus, helping teachers stay informed about global trends and evaluation standards in chemistry competitions. For instance, foreign teaching methodologies such as "Project-Based Learning (PBL)" can be adopted, emphasizing the cultivation of students' independent inquiry skills and teamwork spirit.

4.4 Innovating "Competency-Oriented + Sustainable" Cultivation Mechanisms

The competition evaluation system should incorporate process-oriented indicators such as green synthesis concepts, laboratory safety protocols, and teamwork skills into its scoring criteria to establish more scientific and comprehensive evaluation dimensions. Taking green chemistry competitions as an example, specialized evaluation metrics like "green process design," "waste treatment solutions," and "atom economy assessment" can be introduced in the scoring system to guide students in focusing on the sustainability of chemical processes. Simultaneously, a "research log" system should be implemented, requiring participating teams to meticulously document their experimental design rationale, problem-solving processes, and innovative breakthroughs. This allows judges to dynamically assess students' scientific thinking, innovative capacity, and problem-solving skills. The "National College Student Chemistry Experiment Innovation Design Competition" organized by the Chinese Chemical Society has begun incorporating laboratory safety practices and environmental awareness into its evaluation system, achieving positive results. Chemistry-related science competitions should break down disciplinary barriers by adopting interdisciplinary team formation models, where chemistry majors collaborate with students from materials science, computer science, environmental studies, and other fields to form joint teams. This collaborative approach not only broadens students' knowledge horizons but also cultivates their teamwork and cross-disciplinary communication skills. In practice, a "complementary expertise + task-driven" team formation strategy can be employed. For instance, in a "Novel Functional Materials Design" competition, chemistry students could be responsible for molecular structure design and synthesis, materials science students for performance characterization, while computer science students utilize simulation calculations to optimize material properties. Through clear division of labor, regular communication, and collaborative problem-solving, students can master interdisciplinary collaboration methods and techniques in practice. To prevent the phenomenon of "last-minute cramming before competitions" and ensure continuous improvement in students' research capabilities, it is necessary to construct a tiered training system featuring "basic training for lower grades - project practice for upper grades." This system emphasizes the continuity and systematic nature of research training, enabling students' competency development to follow a spiral upward trajectory. At the lower-grade level, foundational knowledge and experimental skills can be consolidated through activities like "Basic Chemistry Laboratory Skills Competitions" and "Literature Review Report Competitions." For example, the Chemistry Department of Qilu University of Technology holds an annual "Scientific Literature Reading Competition" to lay a solid foundation for advanced research practices. Upon reaching upper grades, students are then guided to conduct comprehensive and innovative research through "Innovative Experiment Projects" and "Industry-Academia-Research Collaboration Projects." The "Research Mentor System" implemented by the Chemistry Department of Qilu University of Technology assigns specialized advisors to each participating student, providing continuous guidance from topic selection to project completion, thereby ensuring the continuity and depth of research training.

5. Conclusions

Optimizing chemistry competition cultivation models is essential for developing NQPF-aligned talents. By updating competition content, deepening industry-academia collaboration, and improving evaluation systems, we can significantly enhance educational outcomes and foster innovation capabilities. Future efforts should explore integrated "competition-research-entrepreneurship" pathways to transform chemical discipline advantages into NQPF development momentum, accelerating China's transition from "chemical power" to "chemical leader". The proposed strategies provide implementable solutions while requiring further refinement through institutional coordination and resource allocation.

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