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Advancement of Applied Chemistry Program through Digital Intelligence Technologies

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Abstract

Driven by the digital age, the chemical and chemical engineering industry is gradually transforming towards green, refined and intelligent development, thus posing new demands on talents' data literacy, innovative thinking ,and interdisciplinary capabilities. Taking the Applied Chemistry major as an example, this paper explores the paths and methods of promoting educational reform and construction through digital and intelligent technologies. First, in the term of teaching modes, personalized and interactive teaching is realized through intelligent platforms and virtual simulation technologies. Second, in the practical system, a new paradigm of "virtual simulation - simulation calculation - physical verification" is constructed. Third, in the course content, new technological elements such as Python, chemoinformatics and artificial intelligence are integrated. Fourth, in the evaluation system, a multi-dimensional and full-process evaluation mechanism is built based on learning data analysis. Fifth, in the faculty construction, teachers are encouraged to transform into "mentors, designers and analysts". Sixth, in professional management, a data-driven decision-making mechanism is established. In conclusion, digital and intelligent technologies will drive the Applied Chemistry major to shift from cultivating traditional "chemists" to nurturing "composite talents in chemistry and data", providing important support for building a high-quality education system.

Keywords

Digital Intelligence Technology; Applied Chemistry; Educational Construction.

1. Introduction

The rapid development of digital and intelligent technologies has transformed numerous business models, prompting various industries to undergo digital, intelligent and smart transformation[1]. Artificial intelligence has rapidly become a focus of attention in higher education reforms. As higher education is a key intersection of the first productive force of science and technology, the first resource of talents, and the first driving force of innovation, its digital transformation is not an "option" but a "necessity". With the rapid development of globalization and the accelerated progress of technology, the chemical industry is facing many new challenges and opportunities. These changes require chemical professionals not only to have a solid theoretical foundation but also to have the ability to deal with many complex practical problems and the continuously changing technological environment. The reform of teaching aims to improve the quality of teaching, so that students can better adapt to future career demands and cultivate more and better professional talents with practical ability and innovative spirit for the chemical industry, thereby promoting a better correspondence between school teaching and enterprise needs.

The Applied Chemistry major is the link connecting basic chemical research and downstream industries. The quality of talent cultivation in this major directly affects the development of numerous industries,including chemical engineering, materials, and energy. Currently, these industries are developing towards the direction of "greening, refinement, and intelligence". Intelligent manufacturing factories, digital twin technology, AI-assisted molecular design and synthesis, high-throughput automated experiments, etc., have become the frontiers of the chemical industry. The demand for talents in the industry has fundamentally changed, that is, from the past requiring only the mastery of knowledge and experimental operations, it has now become necessary for talents to have data literacy, computational thinking, interdisciplinary integration ability, and human-computer collaboration skills. If relevant talents lack the ability to use data analysis and AI tools to solve complex chemical problems, they will lose their core competitiveness in the future workplaces.

2. Digital and Intelligent Technologies Empower the Reform of the Applied Chemistry Major

At present, the empowerment of digital intelligence technology in the reform of the Applied Chemistry program is not a mere superposition, but rather a reshuffling of the current landscape of this discipline. As the most dynamic and critical component of new-quality productive forces, new-type talents are required to possess robust technical thinking, multi-dimensional thinking, and innovative thinking. They should continuously generate new productive forces to provide strong intellectual support for scientific and technological innovation and industrial transformation[2].

How to cultivate high-quality talents? This requires the establishment of a new quality education system. Utilizing digital and intelligent technologies to reform teaching and learning, and strengthening top-level design is necessary. Integrating AI into various disciplines to lead technological thinking, using collaborative entities-driven comprehensive thinking, and fostering creativity to shape innovative thinking, we should cultivate a group of new quality talents capable of adapting to the development of new quality productive forces, thereby injecting continuous vitality into the continuous progress and sustainable development of society. Next, we will elaborate in depth from the following six core dimensions.

2.1. Teaching Model Reform

The core concept is to utilize digital and intelligent technologies to break through the limitations of time and space, enabling personalized teaching for students and integrating learning platforms with teaching methods[3]. For instance, fully adopt learning platforms such as "Superstar Learning Platform", "Changjiang Rain Classroom", and "Wisdom Tree", and construct a teaching model that combines small private online courses (SPOCs) with flipped classrooms. Additionally, teachers can create resource packages such as short videos, small animations, and online documents, and push them through these platforms. The AI algorithms embedded in the system can recommend personalized resources based on students' historical learning data (such as knowledge gaps and interest tags). After students complete their pre-class study, they can take online quizzes, and the system will automatically analyze the students' answers and generate a pre-class study report to be fed back to the teachers.

During the class, there are multiple forms of interaction and real-time feedback: The offline classroom will no longer be dominated by the teacher. Through functions such as bullet screen interaction, multi-party discussion, random name calling, and group tasks, all students can have high-frequency and effective interaction, motivating both teachers and students. Teachers can immediately initiate in-class tests, and the platform will generate answer statistics charts instantly, enabling teachers to precisely identify students' confusion points and provide targeted explanations on the spot, achieving "precise analysis".

After class, consolidation and deep extension: The platform will automatically distribute homework. The AI homework grading system can already handle objective questions and is gradually achieving intelligent grading of short-answer and calculation questions, which will significantly reduce the teacher's workload. The system generates personal knowledge mastery situations based on students' homework and interaction data, marking weak knowledge points and accurately pushing relevant reinforcement exercises and some related extended reading materials.

Virtual simulation (VR/AR/MR) and immersive teaching: It can be applied to high-risk experimental operations, understanding abstract concepts, and cognizing microscopic structures -VR: Build a highly realistic virtual laboratory environment. Students can complete experiments in extreme dangerous environments such as synthesizing toxic gas, exploring rocket fuel propellants, and operating high-temperature and high-pressure reaction vessels through VR glasses and controllers as shown in the picture. The system will strictly record the experimental operation process. Any non-standard or incorrect operation (such as incorrect reagent addition sequence, failure to wear protective glasses, etc.) will trigger an "accident" animation (such as explosion, poisoning, etc.) and provide detailed safety tips, thus training students' safety awareness and standard operation skills in an absolutely safe environment. AR: Students can scan the molecular formulas on textbooks using tablets or AR glasses. A three-dimensional, rotatable, and scalable 3D molecular model will appear in the real world, visually presenting bond lengths, bond angles, electron cloud distribution, and reaction process orbital changes. For complex instruments, AR technology can gradually analyze and display the internal structure and working principle of the instrument in animation form to help students understand its core working mechanism, putting an end to putting an end to "theoretical-only" operations. MR: Teachers and experts can project their holographic images onto the students' laboratory site through MR devices for remote guidance. Students can see the virtual hand shadows of experts placed on their experimental equipment, achieving "face-to-face" precise teaching guidance, which will greatly improve the efficiency of teaching guidance.

2.2. Reconstruction of the Practical Teaching System

The core concept is to break free from the limitations of physical experimental conditions and establish a new integrated practical model of "virtual simulation - simulation calculation - physical verification".

Build a virtual simulation experimental teaching center: Systematically construct it, which covers virtual simulation experiments for various operations such as inorganic synthesis, organic synthesis, analysis and testing, and chemical unit operations. This is not merely the simple digitization of individual experiments, but the establishment of a relatively comprehensive and multi-level online practical teaching system. From the basic "using a balance", "solution preparation" to the more complex "synthesis of aspirin and its characterization" and "performance testing and evaluation of fuel cells", all of these can be completed on the virtual platform. The system of the virtual simulation experimental teaching center has built-in physical engines and chemical engines, which can simulate real experimental phenomena and result data. Students’ virtual experimental operation steps, raw data records, and experimental report quality can all be incorporated into the course assessment system[4].

Introduce digital twin technology: It can be used for medium-sized experiments and process flow teaching. This technology creates a highly similar digital twin for on-campus batch reactors, distillation towers, continuous-flow chemical experiments, etc. Students can freely change parameters such as feed ratio, temperature, pressure, catalyst, etc. in the digital space to conduct process optimization, fault diagnosis (such as tower blockage, leakage, etc.), safety emergency plan drills, etc. The "optimal solution" in the digital space can be sent to the actual equipment for verification in one click. This "first virtual, then real, controlled by virtual" teaching mode can greatly reduce the cost of trial and error, improve the efficiency of practice, and cultivate students' engineering optimization thinking.

AI and data-driven scientific exploration: It can assist in undergraduate graduation projects, research training projects, innovation competitions, etc. Guide students to use machine learning and Python tools (such as Scikit-learn, TensorFlow, PyTorch) to solve chemical problems. For example, predicting molecular properties, constructing ML models, describing the properties of compounds based on molecular structures to predict their melting and boiling points, biological activity, stability, toxicity, etc.; optimizing reaction conditions, using experimental design and optimization algorithms (such as Bayesian optimization), using the minimum number of experiments to quickly find the best temperature, time, catalyst dosage, etc. of the reaction, moving towards the initial stage of "autonomous optimization laboratory".

Spectral data analysis: Train neural network models to automatically identify characteristic peaks from complex spectra and perform compound identification. This enables students to no longer be traditional data "carriers", but data "analysts" and "miners", allowing them to have early exposure to practical operation techniques.

2.3. Optimize the Curriculum and Teaching Content

The core concept is to deeply integrate computational thinking and data literacy into the professional knowledge system, cultivating "chemistry + information" interdisciplinary competence. The specific methods are as follows:

New courses are established to build a new knowledge structure. For example, "Python Programming and Chemical Data Processing" covers basic Python knowledge and libraries such as NumPy, Pandas, and Matplotlib, with a focus on explaining how to use Python programming to process Excel experimental data, draw professional charts, and conduct statistical analysis; "Chemical Informatics" imparts content such as molecular descriptor calculation, molecular database retrieval, molecular docking, QSAR/QSPR modeling, etc.; "Artificial Intelligence and Chemistry" provides in-depth introductions to machine learning and deep learning applications in the field of chemistry, such as retrosynthetic analysis, new material discovery, reaction prediction, etc.; and reform existing courses to revitalize traditional curricula. For example, "Physical Chemistry" can introduce demonstrations and some simple operations of molecular simulation and Monte Carlo methods when teaching thermodynamics and kinetics, allowing students to intuitively observe the movement of these microscopic particles and understand the laws of statistics. "Instrumental Analysis" offers special experiments to teach how to use software to denoise, identify peaks, and conduct quantitative analysis of chromatography and spectroscopy data, even preliminary pattern recognition. "Organic Chemistry" introduces teaching of synthesis analysis software, allowing students to experience computer-assisted synthetic route design, better understand the synthetic route, and deepen the understanding of complex organic compounds.

2.4. Reform of the Evaluation System

The core concept is to utilize learning analytics technology to realize a comprehensive, multi-dimensional, and developmental evaluation based on big data. The specific operation is as follows:

Quantification and deepening of process-based evaluation: The learning platform automatically collects all the data throughout the process, including video viewing duration and navigation, homework accuracy, quality and frequency of forum contributions, virtual experiment operation logs (step sequence, time taken, error count), frequency of classroom interaction, etc.; Virtual experiment evaluation: The system not only can determine the success or failure of the experiment, but also can evaluate its operational standardization, efficiency, cost control awareness (reflected by the consumption of virtual reagents), safety and environmental protection awareness, and generate a detailed ability assessment report;Project-based learning evaluation: Multi-angle assessment of students' code quality, model performance, report innovation, and contribution to team collaboration (analyzed through online collaboration platform logs);Build personalized virtual portraits for each student, and integrate all the above data to construct a data analysis model. For each student, a dynamic and visual "virtual portrait" will be generated;This virtual portrait uses forms such as radar charts to present the student's ability level in multiple dimensions, such as knowledge mastery, practical skills, innovative thinking, collaboration ability, and learning habits. This portrait serves two purposes: for students to enhance self-awareness and self-planning, and the system will precisely push personalized learning resources based on the weak points of the portrait. Teachers and administrators: for targeted tutoring, facilitative teaching, and macro-level diagnosis. This canidentify common weak points among students , thereby optimizing the design of courses and adjusting the teaching content.

2.5. Staff Team Building

The core concept is that the role of teachers will shift from being merely "lecturers" to "mentors, designers, and analysts". The specific methods are as follows:

Provide systematic training: organize a series of professional training sessions covering educational technology theory, platform operation, VR/AR content development, and basic data analysis to alleviate teachers' "technological anxiety";, platform operation, VR/AR content development, and basic data analysis to alleviate teachers' "technological anxiety";Establishing incentive and community mechanisms, incorporating digital and intelligent teaching achievements (such as high-quality online courses, virtual simulation projects, and intelligent teaching cases) into the evaluation systems for professional title promotion, performance appraisal, and rewards. Establishing a "digital and intelligent teaching innovation team", encouraging teachers from different disciplines and colleges to form a community to collaboratively develop teaching resources and share successful experiences;Role transformation, teachers are no longer merely authoritative disseminators of knowledge, but designers of learning situations (designing blended learning processes, developing virtual simulation scenarios, and planning project-based learning tasks), guides for students' growth (based on data profiling, providing personalized academic guidance and career planning suggestions), and analysts of educational data (interpreting learning analysis reports and continuously improving teaching strategies).

2.6. Professional Management and Scientific Decision-Making

The core concept is to utilize big data technology to understand social demands, transforming from "decision-making driven by experience" to "decision-making driven by data", and dynamically optimizing professional development[5].

Conduct big data analysis of talent demand: regularly collect and analyze job information for positions related to "applied chemistry" on mainstream recruitment platforms (such as 51job, BOSS Direct Recruitment, etc.), using natural language processing technology to analyze the frequently occurring technical skills keywords (such as Python, machine learning, CAD, operation of a certain specific instrument, etc.), soft skills requirements, and salary levels, generating a talent demand trend report that serves as the core basis for revising talent training objectives;Tracking and feedback on alumni development, build an alumni information database, and track their career development paths through questionnaires and data analysis. The analysis results will be fed back to the professional guidance teachers, used to evaluate the timeliness of the training plan, forming a complete closed-loop system of "training-employment-feedback-improvement".

3. Conclusion

The wave of digital and intelligent technologies has provided a historic opportunity for the reform and upgrading of the traditional advantageous engineering discipline of applied chemistry. The reform framework systematically constructed in this study indicates that by deeply, organically, and systematically integrating AI, big data, VR/AR, and other digital and intelligent technologies with professional teaching, it may effectively solve many problems that have long plagued the development of the discipline, and build a more secure, efficient, open, personalized, and seamlessly connected smart education ecosystem aligned with industry frontiers.The essence of this transformation is to promote the talent cultivation goals of the applied chemistry discipline from the traditional "chemist" to the future "chemist scientist proficient in data analysis" or "chemical engineer proficient in using digitalization to solve chemical problems". The future graduates of applied chemistry may not only be experts proficient in chemical principles and experimental skills, but also versatile, innovative elites who can proficiently process data using programming languages, utilize machine learning models to predict properties, optimize processes through virtual simulation, and manage through digital twins. They will become the core force leading the intelligent upgrade of the chemical and chemical engineering industry. Looking to the future, with the continuous technological updates, some more advanced applications are worth our anticipation. Blockchain technology can be used to verify the authenticity of experimental data. Emotional computing can be used to analyze students' learning status, thereby providing certain humanistic care. Generative AI (such as ChatGPT, etc.) can serve as a powerful auxiliary tool for learning and work, applied to inspiring innovative thinking, assisting literature reviews and thesis writing (correct guidance is needed, and excessive reliance and abuse should be avoided). The discussions in this paper still need to be continuously tested, adjusted, and improved in specific practices. The digitalization-driven reform of applied chemistry teaching has pressed the accelerator, and it is believed that this educational transformation will bring surprises to everyone in the near future.

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