Exploration of the Undergraduate Training Model for Energy Storage Science and Engineering from the Perspective of New Quality Productivity

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***Abstract*—Energy storage technology is the hub and core technology for the development of new power systems. In order to adapt to the changes in the energy system, the Ministry of Education, the National Development and Reform Commission, and others actively promote the transformation of the talent training system related to energy storage, and promote the construction of the energy storage science and engineering major. Energy storage science and engineering is a "new engineering" major that adapts to the transformation of the energy system and generates new quality productivity. This major has a deep integration and intersection of disciplines, involving many fields such as electrical, materials, electrochemistry, and engineering thermophysics. Firstly, the current situation of energy storage discipline construction in China has been analyzed; Secondly, The talent cultivation goals and ideas of energy storage disciplines with the characteristic of "inter-disciplinary integration" have been elaborated; Finally, focusing on the talent cultivation goals in the field of energy storage, a talent cultivation plan for the energy storage discipline has been constructed along the three dimensions of quality, knowledge, and ability to meet the requirements of the development of new productive productivity.**

***Keywords*—new quality productivity, energy storage science and engineering, curriculum system, talent training model**

I. Introduction

In September 2023, General secretary Xi Jinping first proposed the concept of "new quality productivity" during his inspection in Heilongjiang, emphasizing "the need to actively cultivate strategic emerging industries such as new energy, new materials, advanced manufacturing, and electronic information, actively cultivate future industries, accelerate the formation of new quality productivity, and enhance new development momentum" [1]. In December of the same year, the central economic work conference further called for "promoting industrial innovation through scientific and technological innovation, especially using disruptive and cutting-edge technologies to give birth to new industries, new models, and new driving forces, and developing new quality productivity." [2] The 2024 government work report clearly stated that accelerating the development of new quality productive forces is the top priority of government work. The new productive forces will inevitably bring profound social changes, and the leap in human development forms may be one of the fundamental changes. This means that talent cultivation in the new era will also usher in historic and innovative development. Regarding the connotation of new productive forces, General secretary Xi Jinping pointed out that "new productive forces play a leading role in innovation, break away from traditional economic growth methods and development paths of productive forces, have high-tech, efficient, and high-quality characteristics, and are in line with the new development concept of advanced productive forces. It is born from revolutionary breakthroughs in technology, innovative allocation of production factors, and deep industrial transformation and upgrading. The basic connotation is the leap of workers, labor materials, labor objects, and their optimized combinations, with a significant increase in total factor productivity as the core symbol. The characteristic is innovation, and the key is quality, which is essentially advanced productive forces. As the main battlefield for cultivating innovative talents, universities grasp the future talent needs of industries, proactively determine talent training goals, and do a good job in revising talent training plans." [3] It is an important guarantee for universities to provide high-quality talent support for the development of new productive forces.

With the continuous development of new energy industries such as solar energy, wind energy, biomass energy, smart grid industry, and electric vehicle industry in terms of energy technology revolution and energy consumption revolution, energy storage technology has become an important leading technology driving revolutionary and disruptive adjustments to the global energy landscape. At the same time, the demand for talent in the energy industry in the field of energy storage has shown explosive growth. In order to improve the quantity

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and quality of energy storage talent training, support the development of the energy storage industry, the ministry of education, the national development and reform commission, and the energy administration have issued notices such as the action plan for the development of energy storage technology disciplines (2020–2024) and the work plan for strengthening the construction of higher education talent training system for carbon peaking and carbon neutrality [4–6], requiring the acceleration of the cultivation of "high-precision, sharp and scarce" talents in the energy storage field. Energy storage science and engineering is a "new engineering" major that adapts to the transformation of the energy system and promotes the emergence of new quality productivity, with the characteristic of "interdisciplinary integration". The cultivation of highly skilled and scarce talents in the field of energy storage involves basic knowledge in physics, chemistry, materials, as well as professional knowledge and practical skills in energy power, chemical engineering, automation, and electrical engineering [7, 8]. It is urgent to break down disciplinary barriers and establish a sound energy storage professional knowledge system involving interdisciplinary intersection. Many domestic universities have just established the Energy Storage Science and Engineering major, relying on the construction of different majors such as energy and power, electrical engineering, and engineering thermophysics. The training methods and goals are different, and a mature and complete talent training mechanism has not yet been formed. There are many disciplinary directions in the field of energy storage, but there are significant differences in technologies such as electrochemistry, thermal energy, mechanical, and electromagnetic energy storage, making it difficult to integrate them. In the face of emerging disciplines, the teaching team of energy storage disciplines also lacks a multidisciplinary background in this field. It is urgent to update the knowledge structure, improve the teaching team, and strengthen the construction of a teacher team that integrates industry and education. In summary, compared to the newly established interdisciplinary "new engineering" major in the past, the energy storage science and engineering major presents characteristics of "more basic disciplines", "more professional directions", "less teaching materials", and "fewer experienced teachers", which brings unprecedented challenges to the construction of disciplines and majors. Therefore, this article revolves around the goal of talent cultivation in the field of energy storage, and constructs a talent cultivation plan that adapts to the development requirements of new productive forces along the three dimensions of quality, knowledge, and ability, providing useful references for the construction of energy storage science and engineering majors.

II. Current Situation of Energy Storage Discipline Construction

A. Construction of Energy Storage Discipline

At present, the contradiction between the rapid development of the energy storage industry and the shortage of professional talents in the field of energy storage is becoming increasingly prominent. The construction and development of energy storage disciplines has become a major strategic demand of the country [9, 10]. In order to accelerate the cultivation of "high-precision and cutting-edge" talents in the field of energy storage, the Ministry of Education and other ministries issued "the action plan for the development of energy storage technology disciplines (2020–2024)" in early 2020. The action plan points out that firstly, the talent training system in universities needs to break down disciplinary and professional barriers, accelerate the cross integration and collaborative innovation of multiple disciplines and fields, and improve the construction of energy storage disciplines; Secondly, vigorously cultivate technology research and development talents and industrial application talents; Finally, strengthen the linkage between science and education, integrate industry and education, and promote the organic connection and deep integration of the education chain, talent chain, and industry chain. In the same year, the Ministry of Education added an undergraduate major in energy storage science and engineering, with a major code of 080504T.

Xi'an Jiaotong University established China's first undergraduate program in energy storage science and engineering in February 2020, and many universities have actively responded to the planning of energy storage programs. As of now, 26 universities in 17 provinces and cities have established the "energy storage science and engineering" major. Xi'an Jiaotong University deeply integrates six major disciplines: power engineering and engineering thermophysics, electrical engineering, materials science and engineering, electronic science and technology, physics, and chemistry. In its teaching plan, it has set up seven course groups: mathematical fundamentals, energy storage fundamentals, thermal mass energy storage, electrochemical and electromagnetic energy storage, system energy storage, frontier Lectures, and professional comprehensive experiments, in order to achieve deep integration of basic science, energy science, information science, etc., and to carry out interdisciplinary collaborative talent cultivation around the three modules of thermal mass energy storage, electromagnetic energy storage, and energy storage systems.

B. Main Issues in Professional Construction

In response to the shortage of energy storage professionals, a single knowledge structure of related talents, weak integration of industry and education, and a basic gap in the training of composite talents combined with the new power system, the talent training mechanism for energy storage science and engineering is a "new engineering" experimental field with reform and experimental characteristics. In the process of constructing the energy storage profession, it is necessary to focus on solving some problems in traditional training methods, establishing a new training system that adapts to the characteristics of students, learning methods, teacher abilities, and changes in social needs in the new era. The following three key issues need to be addressed.

(1) How to build a reasonable knowledge system for energy storage subject courses? Traditionally, knowledge learning in specific disciplines follows a gradual and layered approach. The interdisciplinary fields involved in Energy Storage Science and Engineering are more significant compared to previous disciplines. If traditional training systems are used, it is difficult to form a complete talent cultivation in this discipline in the current fast-paced society, and it is impossible to form a knowledge structure and quality ability that can meet the actual needs of the industry in the undergraduate stage.

(2) How to guide students to master necessary engineering basic skills? In the past, in undergraduate education, the curriculum mainly focused on knowledge-based content, with less involvement in the cultivation of students' practical skills. "Emphasizing the Tao over the Technique" has also been a long-term policy of undergraduate education. However, the long-term shortcomings of skills have led to knowledge learning being more like a "cramming style" education. Improving the quality of actual training requires both theory and method to be valued, mutually promoted, and coordinated.

(3) How to strengthen students' experimental practice and innovation abilities? In the traditional training mode, only practical aspects, such as graduation design, involve the application of knowledge and skills. During the training stage, there is a lack of practical experience that is closely related to the application of knowledge and skills, and the bridge of applying what is learned cannot be connected, resulting in a considerable number of graduates lacking corresponding foundations and professional abilities. It is necessary to create sufficient opportunities for students to use their knowledge and skills to solve practical problems, stimulate their self-directed learning, and promote the transformation of basic knowledge and skills into practical problem-solving abilities.

III. Objectives and Ideas for Talent Cultivation in the Field of Energy Storage

A. Talent Training Objectives

Intended to cultivate students with a solid foundation in mathematics, physics, chemistry, chemical engineering, energy, information, power electronics, and other energy storage related knowledge; Master professional knowledge in theoretical and experimental aspects related to energy storage, including materials, devices, systems, intelligent manufacturing, control, processes, testing, and analysis theories and methods; The ability to discover, think, propose, and creatively solve energy storage science and technology problems; Having a healthy body and mind, adhering to scientific ethics, and cultivating a sense of teamwork; Actively facing the forefront of international technology, major national economic and social needs, and playing a leading role in academic, industrial, and management aspects. The recommended common cultivation objectives are as follows.

Objective 1: Possess a correct outlook on life, values, society, and science, with a high level of ideological and moral education, social responsibility, cultural literacy, and professional qualities, and a strong sense of practicality and innovation.

Objective 2: Solidly master the basic theoretical knowledge, professional skills, and application technologies of mathematics, physics, chemistry, and energy storage.

Objective 3: Possess the ability to independently acquire knowledge, practice, research, and develop new technologies.

Objective 4: To receive training in scientific and technological research methods, possess the ability to comprehensively apply basic theories, techniques, methods, and computational simulations to solve practical problems, possess good scientific literacy and systematic thinking abilities, possess good foreign language reading, communication, and writing abilities, and have a good international perspective.

Objective 5: To have a foundation in further education in physics, chemistry, energy and power engineering, electrical engineering, materials science and engineering, chemical engineering, vehicle and transportation, and related disciplines, or to have the ability to engage in related work in teaching, research, technology development, and management in the future.

B. Talent Cultivation Ideas

In order to meet the development needs of China's new power system and the new trend of new engineering construction, starting from the needs of industrial application, we consider the full chain technology requirements – energy storage ontology technology, energy storage application technology, and energy storage control technology to support the comprehensive and integrated construction of energy storage disciplines. Based on our own positioning, we flexibly set different curriculum systems and talent training models around different energy storage talent training goals. We aim to cultivate industrial application-oriented talents and propose a talent cultivation approach that considers three dimensions: quality, knowledge, and ability. We aim to cultivate outstanding engineering talents with high comprehensive qualities, strong professional knowledge, strong comprehensive abilities, and an international perspective in the field of energy storage, who are highly qualified, foundational, and innovative.

According to Fig. 1, it can be seen that the quality dimension includes the concept of carbon neutrality, sustainable development, international perspective, and service awareness that closely follows industrial development; The ability dimension mainly includes the ability to capture cutting-edge knowledge, systematic thinking ability, practical ability to apply mathematical, scientific, and engineering knowledge, and the ability to judge the effectiveness of engineering solutions in the context of globalization, economy, environment, and society. The exertion of personal abilities can not only fully utilize the role of knowledge, but also reflect one's own value. Quality can guide the ability to move in the right direction.

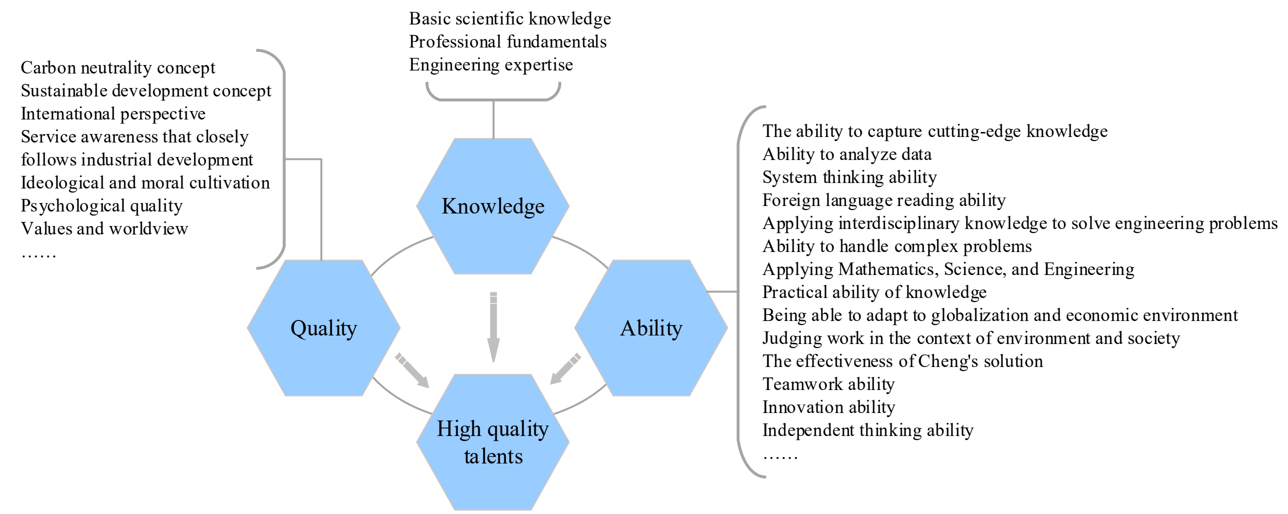

Fig. 1. Three dimensions talent cultivation ideas.

IV. Construction of Talent Training Programs for Energy Storage Disciplines

A. Discipline Direction Positioning

The discipline of energy storage involves a wide range of subjects, and undergraduate training cannot cover all aspects. It is necessary to ensure a certain coverage and find the main direction according to its own characteristics. Therefore, the development goal of a new type of power system with new energy as the main body is to focus on building a knowledge system of energy storage disciplines around four directions: electrochemistry, heat storage, hydrogen energy, and energy storage systems, and to establish a mechanism for cultivating innovative talents and integrating industry and education in the energy storage discipline closely connected to the power storage industry. The overall training plan is shown in Fig. 2. From the first academic year to the fourth academic year, the curriculum system mainly transitions from basic courses in subject categories to professional basic courses, professional core courses, and centralized practical courses. Corresponding professional elective courses are arranged according to specific needs and student abilities.

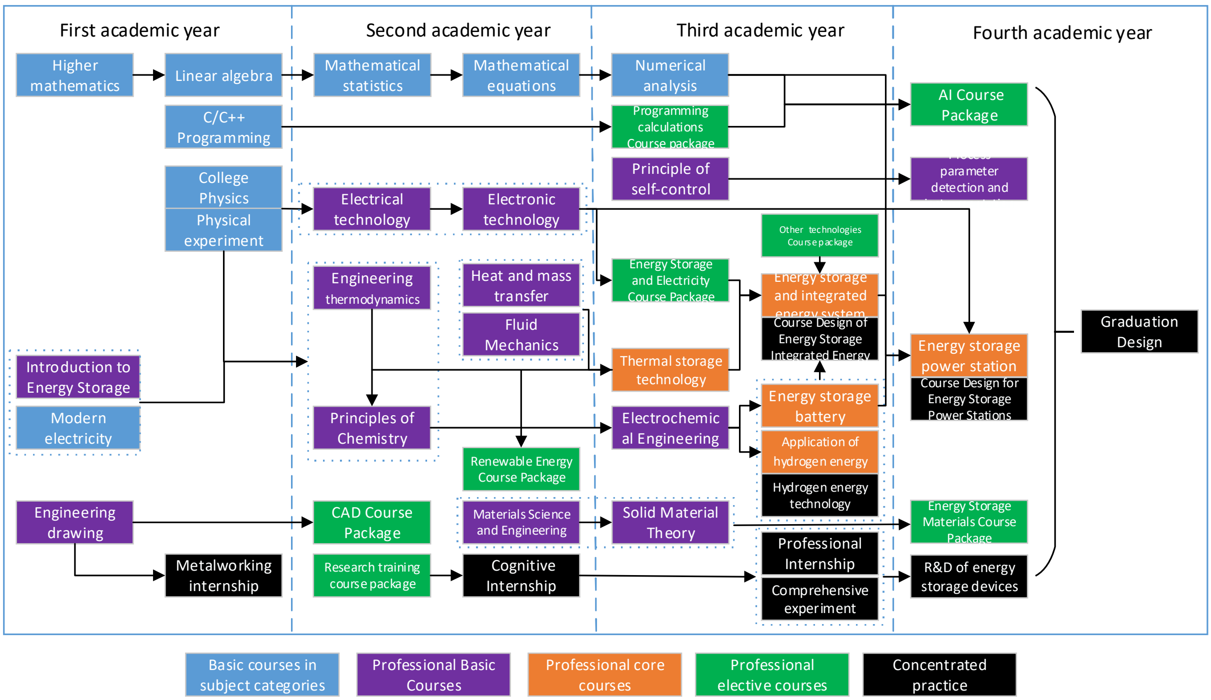

Fig. 2. Ideas for talent training program.

B. Course System Construction

1) Cross knowledge of professional basic courses

Based on the disciplinary direction positioning, the layout of the basic courses in the energy storage major is a combination of engineering thermophysics, chemical engineering, materials, electrical engineering, and control disciplines. The distribution of scientific divisions in each discipline is shown in Fig. 3.

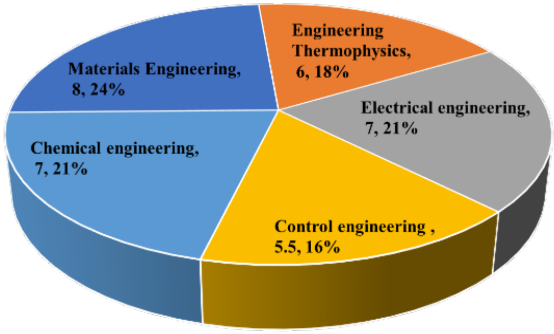

Fig. 3. Interdisciplinary layout of professional basic courses.

The construction of this section of courses takes into account the intersection of professional knowledge and the basic knowledge needs of different fields in subsequent core professional courses. Its characteristics mainly include:

(1) The courses of electrical engineering, control engineering, and engineering thermophysics provide basic knowledge for energy storage and integrated energy systems, as well as energy storage power plant systems. The courses of engineering thermophysics also provide support for thermal storage technology and application courses. The course of chemical engineering mainly provides basic knowledge for core courses such as energy storage battery technology, hydrogen energy technology, and applications. Materials courses provide basic material knowledge for energy storage battery technology, hydrogen energy technology and applications, and thermal storage technology and applications. In addition, courses such as numerical analysis will be added to provide a mathematical foundation for subsequent courses on energy storage and integrated energy systems, as well as energy storage power plant systems.

(2) The curriculum system emphasizes the introduction of energy storage related elements, and some basic courses are taught by energy storage professional teachers, which facilitates the correlation between the course content and the application of energy storage, making the knowledge taught more targeted.

(3) In the process of interdisciplinary integration, there is often a problem of overlapping knowledge points, which needs to be systematically sorted and adjusted. For example, there is a certain degree of overlap between the main basic courses in chemistry, such as physical chemistry, and engineering thermodynamics. Merging basic chemical knowledge into courses on basic principles of chemistry can help related knowledge be more targeted.

2) Coverage and focus of professional core courses

This section of the course includes the expansion of professional courses in energy storage technology and the concentration at the system level. Its characteristics include:

(1) The energy storage technology courses focus on three types: heat storage, batteries, and hydrogen energy, including "heat storage technology and applications", "energy storage battery technology", and "hydrogen energy technology and applications". The principle is to select energy storage technologies with significant distinguishing features and a large number of applications and potentials in the market, so as to cultivate students with a deep and extensive knowledge system.

(2) The energy storage system course includes energy storage power station systems and energy storage and integrated energy systems. Focusing on the course "energy storage power station system", comprehensively teaching the entire system of electrochemical energy storage power stations, including the architecture, configuration, control, management, safety, operation and maintenance of energy storage power stations, connecting the main basic courses, and enabling students to have a comprehensive understanding of energy storage power station systems. The course "energy storage and integrated energy systems" connects the application of thermal, electrical, and hydrogen storage technologies in systems, enabling students to have a clearer understanding of the connections between energy storage, new energy power systems, and various types of energy systems.

(3) The course design of energy storage includes "course design of energy storage power station system", "course design of hydrogen energy technology and application", and "course design of energy storage and Integrated energy system", with a focus on the design architecture ideas of electrochemical systems, hydrogen energy systems, and thermoelectric hydrogen integrated energy systems.

3) Auxiliary role of professional elective courses

The layout of elective courses for energy storage majors is organized according to two main types: skill oriented needs and knowledge expansion needs, including skill mastery courses, new energy knowledge expansion courses, and energy storage knowledge expansion courses. Skills mastery courses include CAD, advanced testing techniques, MATLAB, and introductory undergraduate research; New energy knowledge expansion courses and energy storage knowledge expansion courses include new energy generation, fuel cell technology, mechanical energy storage technology, etc.

The characteristics of professional elective courses include: 1) the focus is to choose through a combination of mentorship and student intention, targeting the specific needs of practical learning and differentiated development of students, achieving targeted and practical application of elective courses, and considering the connection with the skills and knowledge required in the graduate stage in the development of some senior related courses, while also taking into account the need to integrate the undergraduate and master's training process; 2) Encourage teachers with specific research directions to offer short duration energy storage knowledge expansion courses, and improve the selection and proportion of skill based courses. Add elective courses that intersect with other disciplines and technologies, such as new power technology, nanomaterials technology, artificial intelligence technology, etc., in the field of energy storage to promote the cross integration of basic knowledge of energy storage.

4) Connection of practical experimental course system

The practical experiment course system consists of two parts: in class experiments and concentrated practice. In class experiment section: Basic experimental content, including electrical, chemical, materials, and self-control experimental modules, a total of 46 class hours, equivalent to 2.875 credits; The professional course experiment content includes a total of 22 hours of experimental hours, including heat storage, electricity, hydrogen energy, comprehensive energy systems, etc., equivalent to 1.375 credits. The concentrated practice part: energy storage understanding internship, energy storage professional comprehensive experiment, energy storage Professional Internship, scientific research training – energy storage device development and design, a total of 6 credits.

C. Talent Training Mode

The traditional talent cultivation model places more emphasis on theoretical teaching, resulting in students who are prone to high scores but low abilities. The initiative of students in learning is not fully stimulated, and their practical and innovative abilities are weak. In addition, the energy storage industry updates and iterates quickly, so there is easily a significant difference between students' knowledge ability and the actual job requirements in the industry. The combination of industry, education, and research is one of the effective ways to achieve close integration between professional talent cultivation and industry demand, which is more conducive to promoting social development. Therefore, starting from social needs and focusing on the goal of talent cultivation in the field of energy storage, a new talent cultivation model of "school and enterprise cooperation, science and education integration, and 5+4+1 assessment" has been constructed in the field of energy storage, as shown in Fig. 4.

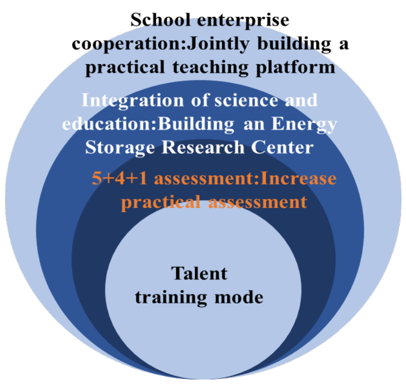

Fig. 4. New talent training model for energy storage discipline.

1) School enterprise cooperation

In the "school enterprise alliance" model, enterprises serve as off campus practical teaching bases, receiving student internships and teacher project training, while universities provide theoretical knowledge learning and experimental venues for students, and work together with enterprises to build practical teaching platforms. Firstly, by introducing engineering projects from enterprises and analyzing multiple projects horizontally and vertically, different levels of experimental teaching are derived, such as basic experiments, comprehensive experiments, design experiments, innovative experiments, etc., forming an experimental teaching system from theory to practice, from passive to active, from knowledge transmission to innovation ability cultivation. Alternatively, after students have mastered a certain amount of basic knowledge, they can participate in horizontal research projects or comprehensive practical projects commissioned by enterprises, guided by the projects, allowing students to participate in the entire process of project application, approval, implementation, etc., comprehensively training students in independent thinking, analysis and problem-solving abilities, as well as scientific research and innovation awareness. Secondly, teachers regularly visit enterprises for project training, timely understanding the difficult problems to be solved in the project, and teaching with the goal of solving problems. The school regularly invites technical personnel from enterprises to give special lectures and engage in academic discussions with teachers and students, enriching the teaching content of teachers. Through the "school enterprise collaboration" model, we effectively collaborate with energy storage research teams of universities, institutions, and enterprises to establish a technology collaborative innovation platform, allowing students and teachers to "go out", bringing in enterprise technical personnel and projects, fully leveraging the advantages of internal and external resources, and promoting talent cultivation, technological innovation, and the transformation of scientific and technological achievements in the field of energy storage through the construction of energy storage science.

2) Integration of science and education

The cultivation of high-quality talents in the field of energy storage cannot be separated from the support of energy storage research. Therefore, transforming research resources in the field of energy storage (including equipment achievements, etc.) into teaching resources is of great significance for talent cultivation. For this purpose, universities can establish advanced energy storage research centers, actively offering cutting-edge courses or lectures in disciplines, and playing the role of scientific research in talent cultivation. Based on scientific research projects, it is necessary to decompose them reasonably, integrate scientific research results into teaching, encourage students to participate in scientific research projects, transfer them from simple textbook knowledge to the hall of scientific research, cultivate independent thinking and innovative thinking, and stimulate their sense of achievement and mission.

3) "5+4+1" assessment

In the context of new productive forces, the cultivation of talents focuses more on quality and ability. In previous teaching, exam scores played a significant role in measuring students' mastery of a certain subject, leading to serious exam thinking among students. The phenomenon of students rushing to focus on key knowledge before the exam and leaving it behind after the exam is common, and their own ability level has not been greatly improved, thus losing the significance of daily teaching. Therefore, we propose a "5+4+1" assessment model, where practical scores account for 50%, mainly including experimental scores, internship scores, and project design scores; Exam scores account for 40%, referring to mid-term or final exam scores; Classroom performance score accounts for 10%, referring to classroom attendance rate, classroom activity level, etc. This assessment model can guide students to attach importance to the cultivation of comprehensive qualities and abilities, enhance their ability to apply theoretical knowledge to solve practical engineering problems, teamwork ability, innovation ability, etc.

V. Conclusion

Developing new productive forces requires a large number of new high-quality talents with high-tech cultural literacy and information literacy, the ability to apply cutting-edge technology, and proficient mastery of various new production tools. This requires universities to actively adapt to the trend of interdisciplinary, multi-disciplinary, and knowledge integration, promote the integration of disciplinary chains, industrial chains, and innovation chains, and carefully formulate talent training plans that match the requirements of new quality productivity. Starting from three dimensions of quality, knowledge, and ability, this article revolves around the goal of cultivating applied talents in the industry, follows the main idea of "interdisciplinary integration" curriculum design, constructs a curriculum education system for energy storage disciplines, proposes a talent training model that combines school and enterprise, science and education integration, and 5+4+1 assessment, and solves the problem of interdisciplinary problems in energy storage disciplines and the disconnection between professional education and industrial development needs caused by the rapid update of the energy storage industry. Promote the deep participation of the energy storage industry, enterprises, and social forces in the talent cultivation process, form a diverse and collaborative education model, and more accurately cultivate outstanding industrial application-oriented talents with high quality, strong foundation, and innovation in the energy storage industry. In the process of energy structure transformation under the "dual carbon" goal, the development of the energy storage industry will still make rapid progress, and the demand for talent in the energy storage field will not be short-term or intermittent, but will be long-term and sustainable. It can be foreseen that in the near future, this interdisciplinary and versatile talent will become the backbone, providing a continuous source of power for the sustainable development of energy storage.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Shuguang Liu proposed the talent training objectives and ideas for energy storage discipline based on the current situation of energy storage discipline construction; Chengwei Wu and Yunyan Zhou proposed the construction of a talent cultivation plan for the energy storage discipline, including disciplinary direction positioning, curriculum system construction, and talent cultivation mode; Hongsheng Wang and Hao Sun drew Figs. 1–4; all authors had approved the final version.

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