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Teaching reform and practice of power battery safety disassembly experiment driven by virtual reality fusion

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Abstract. Aiming at the core pain points in the experimental teaching of power battery recycling, such as high safety risk, difficult to understand the abstract mechanism, and high operation cost, this paper constructs and implements the three-level progressive teaching mode of "theory model practice" based on the self-developed "expansion characteristics disassembly risk classification model". The model transforms the complex electrochemical mechanical mechanism into visual teaching aids through theoretical visualization; Through model simulation, a virtual simulation platform embedded with risk early warning algorithm is developed to realize cost free trial and error in high-risk scenarios; Through the standardization of training, the model threshold is transformed into entity operation specification, and the virtual and real fusion is verified by the sensor system. The practice in the course of new energy vehicle power battery technology in Geely University shows that the teaching mode has significantly improved the students' safety risk prediction ability and the standardization of practice, the pass rate of the course assessment has increased from 75% to 92%, and the average score of the evaluation of safety risk prediction ability has increased by 31.5%, effectively getting rid of the dilemma of experimental teaching in high-risk areas. The virtual reality integration teaching mode formed in this paper is not only suitable for the field of power battery recycling, but also provides a replicable reform paradigm for other high-cost and high-risk engineering experimental teaching.

Keywords: power battery recycling, three step progressive teaching mode, expansion characteristics, safe disassembly, fusion of emptiness and reality

1. Introduction

With the rapid development of the new energy vehicle industry and the advent of the peak of power battery retirement, the green recycling and safe disposal of power batteries has become a key link affecting the sustainable development of the industry. According to the prediction of the Industrial Research Department of the battery recycling Committee of the China Electronic Energy Saving Technology Association, the decommissioning of power batteries in China will reach 820000 tons in 2025; From 2028, the decommissioning volume will exceed 4million tons, and the output value of the waste battery recycling industry will exceed 280billion yuan, which puts forward higher requirements for the number and quality of professional and technical talents in the field of battery recycling [1]. However, at present, there is a structural imbalance of "emphasizing electrochemical principles and ignoring engineering safety practice" in the relevant talent training system in Colleges and universities, which leads to students' insufficient understanding of the mechanical risks in the process of battery disassembly and is difficult to deal with the safety challenges in practical work [2].

Under the background of the current engineering education reform, the virtual reality fusion technology has become an important direction of teaching reform. Scholars at home and abroad have made many explorations in this field. For example, there have been systematic reviews and analyses on the application effect of vr/ar technology in engineering education [3]; In China, there are also research and development of intelligent manufacturing training platform based on digital twins, which provides new ideas for high-risk operation training [4-5]. However, most of the existing research focuses on the construction of general technology platform, and there are still obvious deficiencies in transforming the cutting-edge scientific research achievement system in a specific field into structured teaching resources, especially in the emerging cross field of power battery recycling, which lacks the teaching design scheme that organically integrates the complex mechanism and Engineering safety practice. Based on the specific risk classification model, this research innovatively constructs the "theory model practice" three-level progressive teaching mode, which is precisely to fill this gap and realize the deep integration of scientific research and teaching.

The traditional experimental teaching is faced with multiple difficulties: on the one hand, the high investment cost and safety risk of power battery disassembly equipment make many colleges and universities flinch; On the other hand, abstract mechanisms such as battery expansion characteristics are difficult to intuitively display through conventional experiments, and students lack in-depth understanding of the risk formation mechanism. Although scholars at home and abroad have made important progress in the research of battery expansion mechanism, such as the establishment of mathematical model of thermal expansion of lithium-ion batteries, the proposal of module expansion fatigue accumulation theory, etc., these cutting-edge scientific research achievements have not been effectively transformed into knowledge carriers and training methods suitable for teaching scenes.

In order to solve this problem, based on the self-developed "expansion characteristics disassembly risk classification model", this paper innovatively constructs the "theory model practice" three-level progressive teaching mode. Through systematic teaching design, this mode transforms complex scientific research theories into operable teaching practice, aiming to open up the transformation path from frontier research to engineering application, and provide effective solutions for cultivating new engineering talents with solid safety literacy and innovative practice ability. This paper not only pays attention to the innovation of teaching methods, but also pays more attention to the construction of a complete teaching ecosystem, including the development of visual teaching aids, the construction of virtual simulation platform and the formulation of physical training standards, so as to comprehensively improve the quality and efficiency of power battery recycling talent training.

2. Construction of "three-step progressive" teaching transformation framework

2.1. Transformation concept and overall design

Based on the self-developed "inflation characteristics disassembly risk classification model", a three-level progressive teaching framework of "theory model practice" is constructed (as shown in Figure 1). The framework follows the transformation logic of "deconstructing complex theory - simulating risk situation - standardizing practical behavior", and integrates the frontier scientific research achievements system into the experimental teaching system. The overall design of the framework includes three levels: the basic theory level focuses on the analysis of the relationship between the generation mechanism of expansion force and safety risk; The model simulation layer realizes the dynamic risk drill through the virtual platform; The practical application layer transforms the theoretical threshold into standardized operation specifications. The three levels are linked to form a complete closed loop from knowledge construction to ability training, which effectively solves the core dilemma of high safety risk and difficult to understand abstract mechanism in the teaching of power battery disassembly.

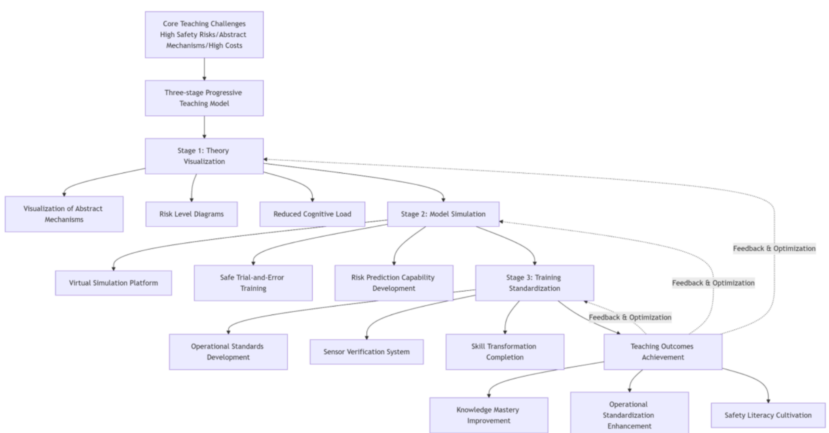

Figure 1. Overall framework of three-level progressive teaching mode

2.2. The first stage: theory concretization

The core task of the theoretical concretization stage is to transform the abstract expansion mechanics mechanism into an intuitive form that is easy to understand and break through the cognitive barriers in traditional teaching.

In terms of content deconstruction, focus on the key parameters and phenomena in the research, focus on the analysis of core concepts such as "reversible/irreversible expansion mechanism", "module stress superposition effect" and "thermal runaway expansion critical point", and establish a direct relationship with the disassembly safety risk. The complex electrochemical mechanical coupling mechanism is decomposed into several teaching units, which effectively reduces the cognitive load of students.

At the tool development level, the interactive animation of "expansion force balance" was designed to dynamically demonstrate the volume change and stress generation in the process of lithium ion de embedding; Draw a "risk classification map" to visually warn the residual expansion force under different state of charge (SOC) and state of Health (soh) in red, yellow and green areas, and visually present the proposed safe operation range. These teaching aids transform abstract theoretical knowledge into concrete learning materials, which significantly improves the teaching effect.

2.3. Phase II: model simulation

The core goal of the model simulation stage is to realize the dynamic exercise and interactive verification of the inflation risk model through virtual simulation technology, and to build a high-risk situational training platform for students for "safe trial and error".

Based on the "expansion force temperature aging" coupling equation and disassembly risk classification algorithm, a virtual simulation platform v1.0 for safe disassembly was developed. The platform has the functions of multi parameter input and real-time response, which can simulate the evolution of mechanical behavior in the process of battery disassembly under different working conditions, and provide students with a high immersion experimental environment.

In terms of scenario design, the platform focuses on restoring three types of typical enterprise high-frequency accident scenarios, including "end plate disassembly stress overrun", "residual force release of cell cutting" and "thermal abuse triggered expansion". Students can independently adjust the state of charge, ambient temperature and disassembly process parameters in the simulation environment, observe the real-time feedback of expansion force change and risk level, so as to deepen the understanding of disassembly safety boundary and systematically cultivate the ability of risk prediction and decision-making under the premise of no physical risk.

2.4. The third stage: training standardization

The core task of the training standardization stage is to transform the safety threshold obtained from theoretical research into executable and quantifiable operation specifications in the actual training, and complete the final transformation from cognition to skills.

In terms of standard formulation, according to the safety threshold verified by experiments, the training manual for the safe disassembly of waste power batteries was prepared, which clearly stipulates that "SOC must be lower than 20% before disassembly" and other specific provisions, so that the theoretical model can be implemented as the operating principle. The manual transforms the complex theoretical model into simple and clear operation specifications to ensure the safety and standardization of the training process.

In the aspect of virtual real fusion, the dynamic monitoring system is constructed by using matrix pressure sensor and infrared thermal analyzer, and the real-time data are collected and compared with the prediction results of virtual simulation. This process not only consolidated the students' understanding of the model, but also cultivated their engineering literacy of scientific decision-making based on data, forming a teaching closed loop of "theory guiding practice and practice verifying theory".

Through the organic connection of the three stages, the teaching framework has realized the complete transformation from theoretical cognition to practical application, and provided an effective way to cultivate engineering and technical talents with solid safety literacy. The framework is not only suitable for the field of power battery recycling, but also has important reference value for the practice teaching of other high-risk industries.

3. Teaching implementation and effect analysis

3.1. Course integration and case implementation

In order to scientifically verify the effectiveness of the teaching mode, this paper uses the quasi experimental research method to integrate the "three-step progressive" teaching framework system into the curriculum system of "new energy vehicle power battery technology" of Geely University, and the implementation cycle is the spring semester of 2024-2025 academic year. In order to ensure the scientificity and comparability of the research, two parallel classes with similar professional background and entrance grades were selected as the research objects. The experimental class (45 students) implemented the new teaching mode, and the control class (43 students) maintained the traditional teaching methods.

In terms of curriculum integration, the following three core modules are mainly constructed:

(1) Basic theory module: integrate the basic theory of expansion characteristics, including reversible/irreversible expansion mechanism, module stress superposition effect and other core concepts;

(2) Virtual simulation module: a virtual simulation system for safe disassembly developed based on unity3d platform, including three types of typical engineering cases;

(3) Physical training module: carry out standardized disassembly practice training relying on the refined green recycling Laboratory of waste power battery resources.

The case design strictly follows the engineering education certification standards and develops three types of representative teaching cases:

Case 1 focused on "end plate disassembly stress out of limit", and trained students to identify structural failure risk based on the 279mpa critical stress data in GuoXuan high tech research;

Case 2 simulates the 0.3kpa/s transient force release process to cultivate students' dynamic risk perception ability for the "residual force release of electric core cutting";

Case 3 focuses on the "early warning of runaway thermal expansion" and combines the research results of linchunjing and others to establish a safety early warning mechanism under the condition of thermal abuse.

3.2. Teaching effect evaluation

This paper constructs a comprehensive evaluation system including three dimensions of knowledge mastery, skill level and literacy cultivation, and uses the mixed research method to evaluate the effect.

In the dimension of knowledge mastery, through the standardized test and concept understanding evaluation, it was found that the score rate of the test questions involving the expansion safety mechanism in the experimental class reached 87.3%, which was significantly higher than 62.5% in the control class ($t=8.32$, $p<0.001$). Especially in terms of high-order cognitive goals, the experimental class showed outstanding performance in solving complex problems such as "quantitative relationship between expansion force and SOC" and "module stress superposition calculation", with the score rate of 85.6% and 82.3% respectively.

In terms of skill level assessment, OSCE (objective structured clinical examination) mode is adopted to design the practical assessment site. The results showed that the one-time pass rate of the experimental class students in the examination of physical disassembly reached 92%, which was significantly higher than 75% before the reform ($\chi^2=9.87$, $p<0.01$). Through video analysis, it is found that the students in the experimental class are better than those in the control class in terms of operation standardization, accuracy of risk prediction and rationality of emergency disposal.

The questionnaire survey using the Richter five point scale showed that 95.6% of the students believed that the new model significantly improved the ability of safety risk prediction ($M=4.52$, $SD=0.63$), and 93.3% of the students believed that it enhanced the awareness of standardized operation ($M=4.48$, $SD=0.59$). Qualitative analysis found that students generally reflected that "the risk-free trial and error environment provided by virtual simulation effectively reduced learning anxiety" and "visual teaching aids made abstract concepts concrete".

In addition, through the follow-up evaluation for half a year, it was found that the students in the experimental class showed stronger engineering practice ability in the subsequent enterprise internship. In the evaluation of enterprise tutors, 88.9% of the students in the experimental class received the "excellent" rating, which was significantly higher than 67.4% of the control class. This shows that the "three-step progressive" teaching mode not only improves the immediate learning effect, but also promotes the long-term development of engineering ability.

The effectiveness of this teaching mode is mainly reflected in three aspects: first, it reduces the cognitive load through theoretical visualization; Second, virtual simulation provides a safe skill training environment; Third, standardized training ensures the effective transformation from theory to practice. These advantages together constitute the key factors to improve the quality of teaching.

4. Discussion and enlightenment

4.1. Effective mechanism of teaching transformation path

The successful practice of the three-level progressive framework of "theory model practice" has verified the effective path of transforming scientific research achievements into teaching resources. The framework constructs a complete teaching closed-loop system through the orderly connection of three stages. Specifically, in the stage of theory visualization, the abstract mechanism of inflation mechanics is transformed into an intuitive cognitive model through visual tools, which effectively reduces the cognitive load of students; In the model simulation stage, the security drill of high-risk scenarios is realized with the help of virtual platform, which breaks through the security restrictions of traditional experiments; In the training standardization stage, the effective transformation from theoretical knowledge to practical skills is ensured through standardized operation process and real-time monitoring system.

The teaching evaluation data show that the transformation path shows significant effectiveness in three key dimensions: first, it follows the constructivist theory and the cognitive development law of "concrete abstract concrete", and constructs a spiral learning path; Second, it establishes a two-way feedback mechanism between theory and practice, realizes "legitimate marginal participation" emphasized by situational learning theory through the integration of virtual and real, and promotes deep learning through the integration of virtual and real; Third, a multi-dimensional ability evaluation system has been formed, which realizes the coordinated development of knowledge understanding, skill mastery and literacy cultivation. The significant improvement of students' high-level cognitive ability and engineering practice ability in the experimental class, especially the outstanding performance in the dimensions of complex problem solving and emergency disposal, fully verified the effectiveness of this path.

4.2. Innovation value and promotion prospect

This paper has achieved innovative breakthroughs in multiple dimensions. The grading model of "expansion characteristics disassembly risk" constructed at the theoretical level not only fills the blank of mechanical safety research in the field of power battery recycling, but also provides a scientific basis for the reconstruction of the curriculum system. A series of teaching tools developed at the method level, including the "expansion force balance" animation, virtual simulation platform and real-time monitoring system, have formed a complete set of teaching technology solutions, especially in the process evaluation to realize the quantitative analysis of operation behavior. The scientific research feedback teaching mechanism established at the mode level makes the frontier scientific research achievements become the core engine driving the teaching reform.

This mode has outstanding replicability and scalability. Specifically, in the field of high voltage electrical engineering, a safe operation training system can be established based on the discharge characteristics; In the field of chemical safety, emergency response training programs can be developed based on reaction kinetic parameters; In addition, in the field of aerospace, this mode can also be combined with structural mechanical properties to build a fault diagnosis teaching system. This cross domain application potential reflects the universal value of this research method.

It should be pointed out that the promotion and application of this mode needs corresponding supporting conditions. Based on the implementation experience, it is suggested to focus on three aspects: the necessary investment in experimental equipment, the construction of double qualified teachers and the reconstruction and optimization of the curriculum system. In terms of promotion strategy, it is suggested to adopt the phased implementation path, give priority to the pilot projects in engineering majors with basic knowledge, and gradually expand the scope of application. At the same time, it is necessary to establish a continuous improvement mechanism to adjust the teaching mode adaptively according to the characteristics of different majors to ensure the maximization of the reform effect.

This study provides important enlightenment for engineering education in the new era. First, the deep integration of scientific research and teaching is an effective way to improve the quality of personnel training; Second, the combination of virtual and actual teaching mode is the key means to solve the problem of high-risk practical training; Third, the systematic transformation framework is the institutional guarantee to realize the teaching of scientific research achievements. These experiences have important reference value for promoting the construction of new engineering courses and cultivating innovative engineering and technical talents, and also provide a reference implementation paradigm for teaching reform in related fields.

5. Conclusion

Aiming at the core pain point of power battery recycling experimental teaching, this paper constructs and practices a three-level progressive teaching mode of "theory model practice" with the core of "expansion characteristics disassembly risk classification model". Through the organic connection of theory visualization, model simulation and training standardization, the dilemma of high-risk and high-cost experimental teaching has been effectively solved. Teaching practice data show that this mode can significantly improve students' knowledge mastery, practice standardization and safety literacy, and has good potential for cross domain promotion.

Future work will focus on two aspects: first, expand the scope of application, verify and improve the mode in different colleges and engineering majors; Second, deepen technology integration, explore the application of artificial intelligence technology in personalized learning path planning and adaptive evaluation, and further promote the development of Engineering Education in the direction of intelligence and accuracy.

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