DESIGN AND DEVELOPMENT OF A SELF-LEARNING COURSE ON BATTERY MATERIAL RECYCLING

Lappeenranta–Lahti University of Technology LUT

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Examiners: Adjunct Professor Kari Myöhänen,Adjunct Professor Xinjian Liu

ABSTRACT

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With the rapid development of the electric vehicle industry and the approaching peak of power battery retirement, battery material recycling has become a critical issue for resource circulation and environmental protection. The focus of the work is systematically exploring the current status and development trends of battery material recycling technologies.

By integrating the design principles and development methods of self-learning courses, this research developed a self-learning course on battery material recycling, focusing on sustainable practices in the electric vehicle industry. The course covers key topics such as material classification, recycling processes, and emerging technologies, using text, videos, and animations. Implemented on an online platform with interactive features, it was evaluated positively for enhancing students' knowledge and practical skills. This study offers a structured model for online education in technical fields and emphasizes the importance of resource recovery. Future work will focus on optimizing content and expanding the course's reach.

Keywords: Battery Material Recycling, Self-Learning Course, Course Design, Online Education, Resource Circulation, Environmental Protection, Electric Vehicles

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1 Introduction

In recent years, with the continuous depletion of non-renewable energy sources and the rapid development of electric vehicles, the recycling and utilization of battery technologies have become the mainstream of research, with lithium-ion batteries becoming the most dominant energy storage technology. However, with the increasing demand for lithium-ion batteries in human society, the recycling of end-of-life lithium-ion batteries has emerged as a critical issue, posing both environmental risks and economic challenges. According to a recent study, it is expected that by 2030, the global accumulation of waste lithium-ion batteries will exceed 8 million tons(Baum, 2023), which will have a huge impact on the ecological environment of the present society. If we do not adopt an effective recycling strategy, valuable resources such as lithium (Li), cobalt (Co), and nickel (Ni) will be wasted, and the resulting hazardous substances will lead to environmental pollution and health risks. Current recycling technologies for lithium batteries are mainly classified into two categories. Pyrometallurgy involves high-temperature smelting to recover metals such as cobalt and nickel, but it is energy-intensive and typically results in low lithium recovery. (Makuza et al.,2021) Hydrometallurgy, on the other hand, uses acid leaching to extract valuable metals and offers high recovery efficiency, although it requires complex waste treatment processes. There are also some emerging as well as traditional recycling technologies such as electrodialysis and laser material processing recycling technologies, but these recycling technologies have certain limitations: the first is that current recycling technologies mainly focus on high-value metals such as cobalt and nickel, but the recovery efficiency of lithium is very low, which leads to a lot of wasted resources(Chen, Zhang and Li, 2024). Traditional hydrometallurgical methods produce large amounts of chemical waste that can cause irreversible harm to the environment, and we need more environmentally friendly and cost-effective alternatives (Harper, G., et al. 2019). These have certain limitations. However this is common for all recycling, not just emerging technologies. Although the technology for lithium battery recycling is evolving in industry, there is a lack of structured educational resources for a wider audience.(Mayyas, A., Steward, D., & Mann, M. 2019)

The aim of this thesis is to develop a Massive Open Online Course (MOOC) to increase

public awareness and technical knowledge of lithium battery pack recycling by analyzing existing lithium battery recycling technologies, evaluating existing lithium battery recycling technologies, and exploring future trends in lithium battery recycling. The course will include the essential elements of lectures, exercises and quizzes to provide an interactive and engaging learning experience.

2 Overview of Related Studies

2.1 Background and significance of the study

2.1.1 The Importance of Battery Material Recycling

With the transformation of the global energy structure and the rapid development of the new energy automobile industry, the demand for lithium-ion batteries as the core power source is growing rapidly (International Energy Agency, 2022). However, due to the limited service life of lithium-ion batteries, disposing of discarded lithium-ion batteries has become a problem. Waste batteries contain precious metals such as lithium, cobalt and nickel, which can be effectively reduced if they can be efficiently recycled. (Fan, E., et al. 2020) Meanwhile, batteries also contain harmful substances such as electrolyte and diaphragm, which, if not properly handled, will cause irreversible and serious pollution to soil and water(International Energy Agency, 2022). Therefore, the recycling of battery materials has become the focus of global attention.

2.1.2 Advantages of self-study programs

Under the background of the continuous development of information technology, online education is rapidly popularized, and self-learning has become a new trend in college education.

Compared to traditional classroom teaching, self-learning offers several notable advantages. It promotes learner autonomy, allowing students to set their own pace and choose learning content according to their individual schedules, which increases both flexibility and efficiency. Additionally, intelligent recommendation algorithms can provide personalized content based on learners' interests and prior knowledge, enhancing engagement. Self-learning also improves accessibility by removing time and location constraints, reducing costs, and enabling broader access to educational resources. Finally, various interactive features, such as online forums, automated assessments, and question-and-answer systems, support active engagement and enrich the overall learning experience.

In view of the current situation that there are few training channels for professionals in the field of battery material recycling and the curriculum system is not perfect, designing a set of systematic and modular self-study courses can help make up for the shortcomings of traditional education and improve the public's cognition and skill level in this field(Sangrà, A., Vlachopoulos, D., & Cabrera, N. (2012), especially college students.

2.1.3 Purpose and significance of the study

This study aims to build a self-learning course platform for battery material recycling for college students based on the key technology system of battery material recycling and the modern online education concept. The specific objectives of this study are as follows. First, to systematically organize and present the core knowledge of battery material recycling, including technical routes, processing procedures, and recycling methods. Second, to construct a sustainable course structure that effectively integrates course content, learning activities, and platform functionalities. Finally, to verify the effectiveness of the course in enhancing students' professional competencies and practical skills through application and evaluation.

2.2 Domestic and international research status

2.2.1 Battery Material Recycling Technology Research Status

The research progress of battery material recycling technology is closely related to the explosive growth of the new energyelectric automobile industry. With the arrival of the global peak of power battery decommissioning, recycling technology has developed from the early simple physical treatment to today's multi-technology integration system. The current mainstream recycling technologies mainly include pyrometallurgy, hydrometallurgy and biological metallurgy, and all kinds of technologies show significant differences in recovery efficiency, economy and environmental impact.

From the perspective of technological development, battery recycling technology has experienced obvious intergenerational evolution. The first generation technology (2010-2015) is

mainly based on high-temperature melting and other thermal processes, although the processing capacity is large but the energy consumption is high; The second generation technology (2016-2020) turns to the hydrometallurgical route and realizes the efficient recovery of metals through the acid-leaching and extraction process; The current third generation technology (2021-present) focuses more on the development of environmentally friendly processes, such as bioleaching and direct regeneration technologies. The evolution of this technology route reflects the industry's shift from simply pursuing recovery rates to taking into account both economics and environmental protection.

Table 1. Comparison of main battery recycling technical parameters

Technical index	Pyrometallurgy(Wang, Gaustad, and Babbitt, 2016)	Hydrometallurgy(Chen, Ma, Luo, and Zhou, 2021)	Bio-metallurgy(Mishra et al., 2008)	Direct regeneration technique
Metal recovery (%)	85-92 (Li:70-75)	90-95 (Li:85-90)	75-85 (Li:80-85)	88-93 (Li:90-95)
Energy consumption (kWh/kg)	8-12	5-8	3-5	4-6
Investment cost (€/ton)	15-50	10-18	8-10	13-16
Processing cycle	4-6h	24-48h	7-15days	8-12h
Secondary pollution risk	high	Medium	low	Very low

From the Table 1, we can see that in terms of metal recovery, hydrometallurgy and direct regeneration technology perform best, the overall metal recovery rate reaches 90-95% and 88-93%, respectively, and the recovery efficiency of lithium is more than 90%. In contrast, the recovery efficiency of lithium by pyrometallurgy is low, only 70-75%. This shows that for recycling scenarios with high demand for lithium, wet and direct regeneration technologies are

more advantageous.

Secondly, in terms of energy consumption and environmental performance, the energy consumption of bio-metallurgy and direct regeneration process is the lowest, respectively, 3-5 kWh/kg and 4-6 kWh/kg, far lower than the 8-12 kWh/kg of pyrometallurgy. In particular, direct regeneration technology repairs the crystal structure of materials without completely decomposing them. This process significantly reduces energy consumption and minimizes secondary pollution.(United Nations Environment Programme UNEP , 2021) The risk level of secondary pollution has been rated as "very low," demonstrating the outstanding advantages of this method in green recycling.

From the perspective of investment cost, the unit treatment cost of bio-metallurgy is the lowest (8-10 €/ ton), which is suitable for resource-limited or small and medium-sized enterprise applications; The cost range of pyrometallurgy is wide (15-50 €/ ton), which mainly relies on scale effects. Although the cost of direct regeneration technology is moderate (13-16 €/ ton), considering its high recovery rate and low pollution characteristics, it has good promotion potential in terms of technology and economy. In terms of treatment cycle, fire metallurgy and direct regeneration technology react quickly, only 4-12 hours, suitable for large-scale industrial treatment; Hydrometallurgical processing time is relatively long (24-48 hours); The biological metallurgy treatment cycle is the longest (7-15 days), and it is mainly used in environmentally friendly test projects or specific ecological scenarios.

2.2.2 Current status of research on self-study course development

Research on the development of self-learning courses primarily focuses on three key areas. The first is course design, which encompasses the definition of course objectives, the organization of course content, the structuring of the curriculum, and the design of learning activities. The second area is platform development, involving the design of platform functions, the layout of the platform interface, and the technical implementation of the platform itself. Finally, course evaluation is an essential component, including the establishment of evaluation indicators, the selection of evaluation methods, and the analysis of evaluation results.

At present, the development of self-study courses has achieved certain results, but there are

still some shortcomings, such as: The quality of existing self-learning courses varies significantly, with some lacking rigorous pedagogical design, which limits their effectiveness and learner engagement, resulting in low quality of courses, which is difficult to meet the needs of students.

Difficulty in guaranteeing learning effects: Self-learning courses lack effective monitoring and evaluation mechanisms, resulting in difficulty in guaranteeing learning effects. (Jensen, L., & Konradsen, F. 2018) Insufficiently in-depth application of technology: the application of information technology in some of the self-study courses is insufficiently in-depth, making it difficult to give full play to the advantages of self-study courses. (Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. 2020)

2.3 Research content and methodology

2.3.1 Content of the study

The main contents of this research are as follows. First, the study investigates battery material recycling technologies by analyzing the current status, technical routes, and development trends within the field. Second, it focuses on the design of a self-learning course for battery material recycling, including the formulation of course objectives, the development of course content, the structuring of the curriculum, and the planning of corresponding learning activities.

2.3.2 Research methodology

This study first conducts a literature review of battery material recycling technologies at home and abroad, providing a basis for the development of courses by exploring related research. Secondly, it studies the existing self-study courses, analyzes the advantages and disadvantages of self-study courses, and improves them in the development of courses. Finally, in the form of classroom tests, the knowledge of the course is applied to practical situations to examine students' mastery and evaluate the effectiveness of the course.

3 Battery Material Recovery Technologies

3.1 Classification and composition of battery materials

Battery materials can be divided into five key parts: cathode materials, anode materials, electrolytes, separators and casings.

Among them, the selection of positive and negative electrode materials will directly affect the energy density, cycle life and overall safety of the battery. Graphite is one of the most widely used anode materials at present. Although its capacity is relatively low, it has a lower cost and better cycle performance. Another common anode material is lithium titanate ($Li_4Ti_5O_{12}$), which is renowned for its excellent cycle life and strong safety characteristics. However, compared with other anode materials, it offers a lower energy density.

The transport of lithium ions is accomplished through the electrolyte in the battery, so the electrolyte of the battery directly affects its conductivity, stability and safety. Under normal circumstances, the battery electrolyte is composed of a mixture of organic solvents and lithium salts, which helps lithium ions move between the electrodes. The separator between the positive and negative electrodes is generally made of polyolefin microporous membrane, as this separator can prevent short circuits, has good safety, and can effectively extend the battery cycle life.

As the outer protective layer of the battery, the casing is usually made of steel or aluminum, which can maintain the structural integrity of the battery and ensure its safety during operation.

3.2 Battery material recycling process

The recycling of lithium-ion batteries is divided into three stages: pretreatment, separation and purification, and material regeneration. These three stages not only affect the efficiency and cost-effectiveness of the final recycling process, but also influence the pollution impact generated during the recycling process

3.2.1 Pre-treatment

Pretreatment is the initial phase in the recycling process, focused on safely handling and partially separating the components of used batteries in preparation for the subsequent purification stage. Several key operations are involved in this step.

The first operation is discharging, which ensures that any remaining power in the used battery is completely released. This is crucial to avoid potential safety risks, such as short circuits, thermal runaway, or explosions during the later stages of recycling. Following this, the disassembly phase occurs, where the battery casing is removed either manually or through mechanical methods, providing access to the internal core components.

Following disassembly, the battery is crushed into small particles to improve the efficiency of material separation. Finally, the separation process uses physical methods to classify the crushed materials, achieving an initial separation of the positive and negative electrode materials, membranes, electrolytes, and other components.

3.2.2 Separation and purification

After the pretreatment is completed, valuable metal elements need to be extracted from the sorted material by certain chemical or biological means. This stage is key to the recycling process, and common methods include:

Pyrometallurgy: Metal oxides are reduced by high temperature heat treatment, converted into elemental metals, and further refined. This method has large processing capacity but high energy consumption.

Hydrometallurgy: The metal is dissolved by acid and base solution, and then pure metal is extracted by extraction, precipitation, electrolysis and other processes, which has the advantages of mature process and high recovery rate.

Biometallurgy: The use of microbial metabolism of metals, dissolved in the liquid phase, followed by the same physical and chemical means to achieve purification. This method is environmentally friendly, but the reaction period is long.

Different extraction methods are suitable for the recycling needs of different types of batteries and metal components, and should be selected according to material characteristics in actual industry

3.2.3 Material reuse and regeneration

Material recycling is the final link of the entire recycling process, and the goal is to reprocess the recycled metal elements into the functional materials required by the battery, so as to realize the closed-loop utilization of resources. It mainly includes the following three aspects:

Cathode material regeneration: the extracted lithium, cobalt, nickel and other metal elements are re-synthesized into ternary materials, lithium iron phosphate and other common cathode materials.

Anode material regeneration: carbon based materials such as graphite and silicon are recycled and prepared into graphite anode or silicon carbon composite materials.

Electrolyte regeneration: Organic solvents and lithium salts in electrolytes are recovered by separation and purification and reformulated into usable standard electrolytic liquid systems.

Through the scientific regeneration process, not only can greatly reduce the raw material cost of new material preparation, but also effectively avoid the environmental discharge of waste, and achieve the dual goals of resource recovery and environmental protection.

3.3 Summary of Battery material recycling technology

Table 2. Three mainstream battery material recycling technologies

Technology type	Main principle	Common method	advantage	disadvantage	Applicable object
Pyrometallurgy	Reduced metal oxides at high temperature are elemental	High temperature melting, vacuum distillation	Large processing capacity, fast response, high recovery rate	High energy consumption, heavy pollution, poor lithium recovery	Ternary material containing cobalt and nickel

	metals				
Hydrometallurgy	The metal is dissolved and purified by an acid-base solution	Acid leaching, alkali leaching, extraction, precipitation, electrolysis	Low energy consumption, less pollution, strong adaptability	Long process and low recovery of some metals	Various battery types, especially suitable for lithium recovery
Biometallurgy	Metal dissolution is facilitated by microbial metabolism	Biological leaching, biological adsorption, biological precipitation	low energy consumption	Long cycle, low efficiency, low technology maturity	Environmentally friendly

4 Design and Development of the Self-Learning Course

4.1 Self-learning course platform design

The Battery Materials Recycling Self-Learning Course is delivered through the Moodle platform and is specifically tailored for undergraduate students pursuing studies related to energy and materials science. The selection of Moodle as the course platform is based on its high degree of openness, modular flexibility, and compatibility with diverse learning tools. As an open-source learning management system, Moodle supports scalable deployment, customizable course structures, and extensive plug-in integration, which together enable the delivery of an engaging and accessible online learning experience.

The course is designed as a four-tiered progressive structure using “basic cognition - technical analysis - case application - frontier exploration” which suits the mental developmental stage of the learners, and can be gradually learned. Basic module gives a general introduction on the physical and chemical properties of key battery material, so that student have a basic idea about these materials. Technical Methods Module outlines the full process of

pyrometallurgy, hydrometallurgy, and biometallurgy, and each sub-topic is accompanied by relevant media to make these abstract technical terms real.

In order to have more diversified learning, this course uses a multi-modal kind of content. Text material isn't just digital conversion, but rather is remolded for mobile-first reading habits and arranged for understanding. Quizzes, as well as real-time feedback, and Q&A section so to encourage student participation and grasp of key concepts are available. It can guarantee that students will no longer be mere recipients of information, but active participants in the knowledge-acquisition process.

The moodle platform is used to fully support learning in a collaborative and self-directed way. Each unit contains a "main task + branching exploration" setup, where students finish basic tasks and can choose to do additional tasks. The teacher also looks at analytical data to see if the student is going as good as they should and tailors there to feedback they are giving them.

4.2 Design of Course Content

This self-learning course in battery material recycling adopts a four-level progressive structure of "basic cognition - technical analysis - case application - frontier exploration", which not only systematically covers the theoretical and technical points of the whole recycling process, but also takes into account the cultivation of practical ability and innovative vision.

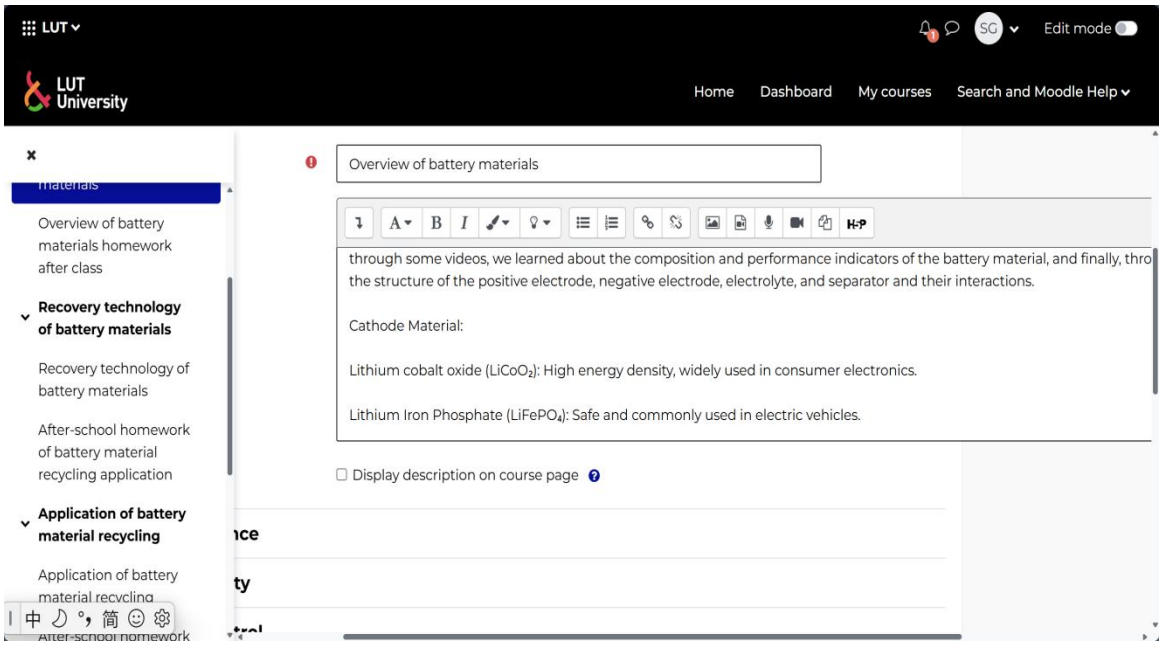

Figure.1 Overview of Battery Materials

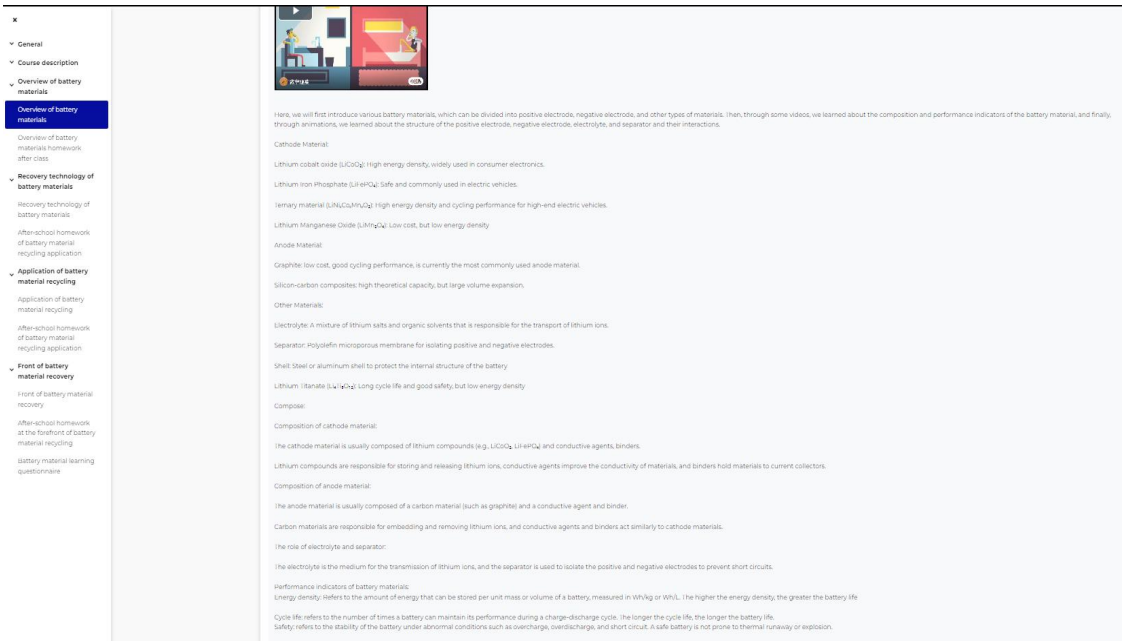

Figure.2 Overview of Battery Materials

This module serves as the foundation of the entire course, introducing the structure and properties of common battery cathode materials. As shown in Figure 1 and 2. The material properties and functions of battery cathode, electrolyte and separator are introduced. Comparative analysis of different types of batteries, including energy density, safety, cost and other indicators; which helps students to establish a knowledge framework of materials science

and enhance their understanding of the objects involved in subsequent recycling technology. After the completion of the study, students can master the basic classification and performance differences of mainstream battery materials, and have the initial analysis and recognition ability, laying the cognitive foundation for the technical module. This module is the starting point of the course, focusing on helping learners establish a basic understanding of battery material systems.

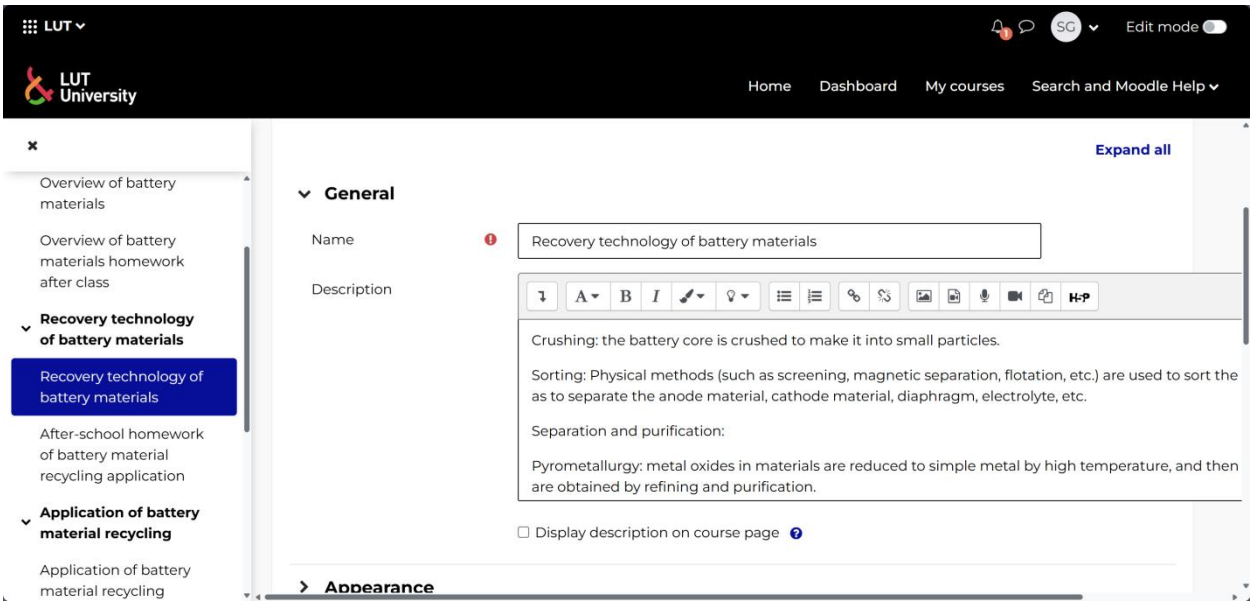

Figure.3 Recovery Technology of Battery Materials

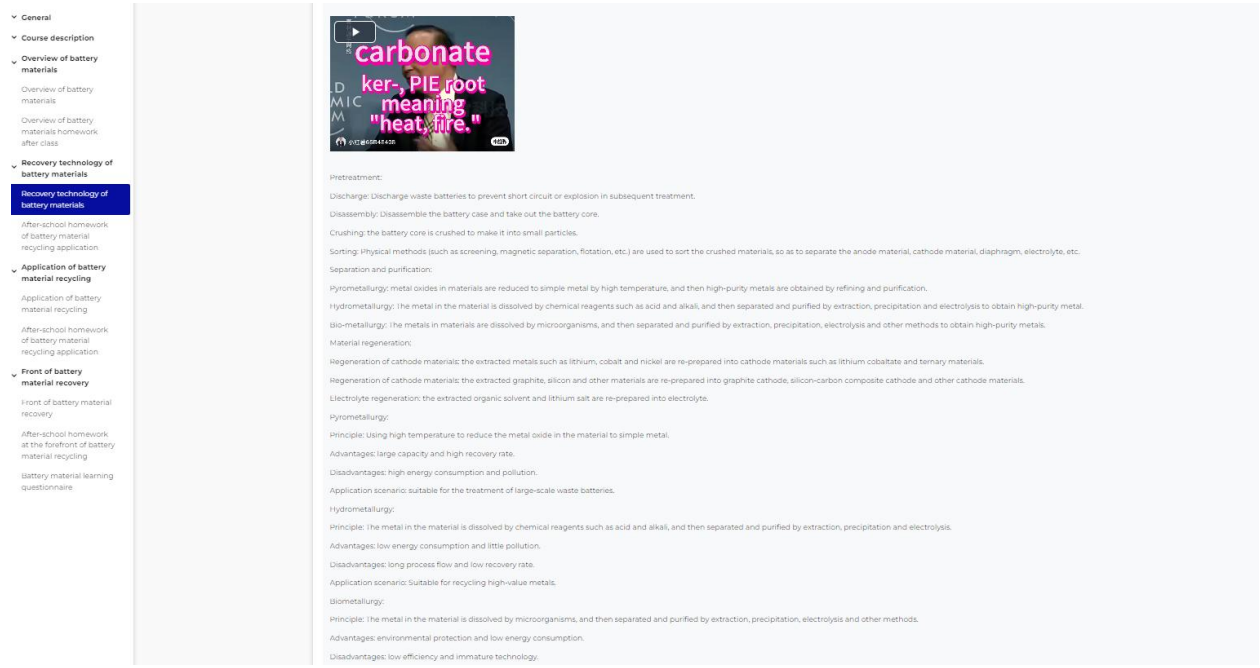

Figure.4 Recovery Technology of Battery Materials

This module focuses on the battery recycling process and systematically teaches key technical principles and operational processes such as pre-treatment. As shown in Figure 4. Each technology is presented with visual video and process flow chart. This chapter is the core part of the course and helps students understand the scope, advantages and limitations of different recycling technologies. Through comparative analysis of the three processes, students can master the principle of metal extraction, process selection basis and equipment configuration logic, and improve the ability of engineering thinking. After training, students will be equipped with the ability to initially design recycling processes.

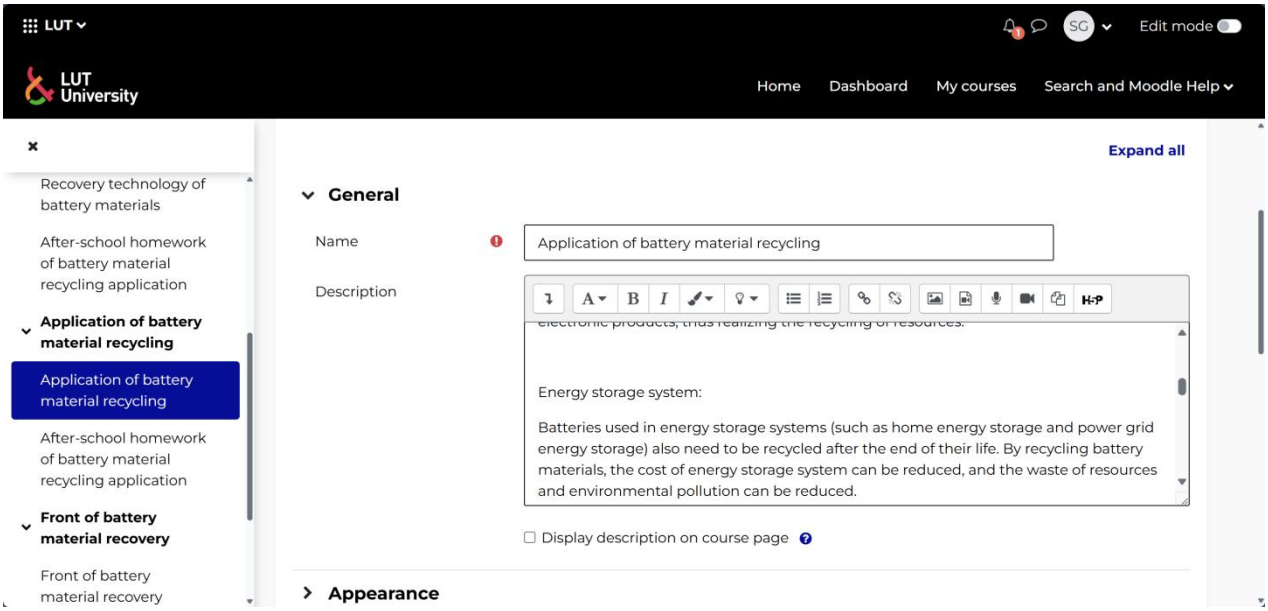

Figure.5 Application of Battery Material Recycling

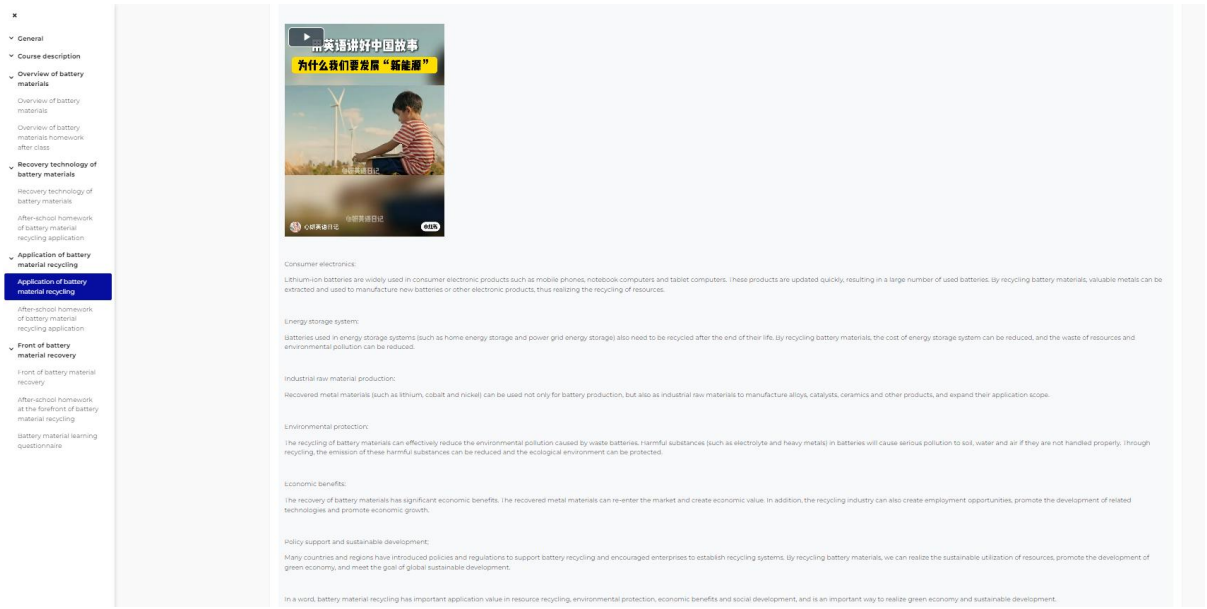

Figure.6 Application of Battery Material Recycling

As shown in Figure 5 and 6, this chapter shows the recycling path of recycled materials by analyzing typical application cases such as household batteries, electric vehicle batteries, and energy storage systems. (Kolodner, J. L.1993) Students will engage in task-based learning, such as case reproduction, recycling process design, and economic analysis. The purpose of this chapter is to improve students' ability to translate theoretical knowledge into practical problem solving. Through the analysis of real industry cases, students can master the design method of recycling process, improve students' comprehensive application ability and team work ability.

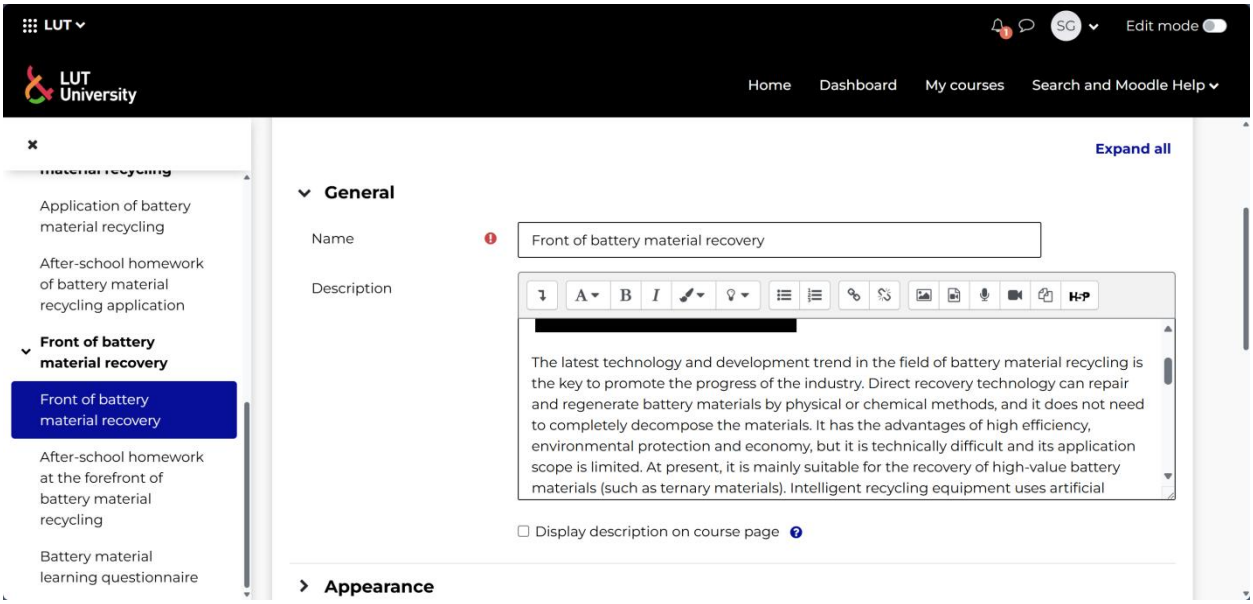

Figure.7 Front of Battery Material Recovery

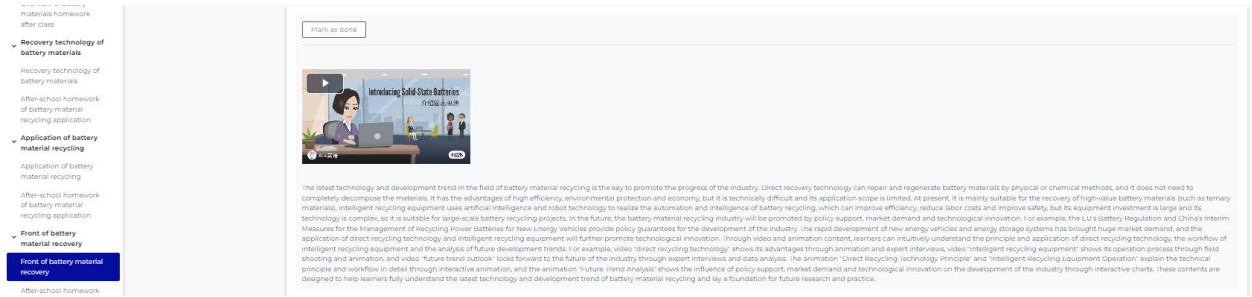

Figure.8 Front of Battery Material Recovery

As shown in Figure 8, This session introduces the latest developments in the field of battery recycling, such as direct recycling technology and intelligent identification recycling equipment. The policies, regulations and trends of battery recycling are also analyzed. This can guide students to pay attention to the future trend of battery recycling. Through the understanding of

the battery recycling industry, students can more truly understand the practical significance of recycling batteries, improve their awareness of sustainability, and then contribute their own strength to sustainable development.

5 Implementation and Evaluation

5.1 Course application

5.1.1 Application Objects

The application objects of the self-study course on battery material recycling mainly include college students, employees of enterprises and members of the public.

As undergraduate and graduate students majoring in battery material recycling related fields, they can learn the theoretical knowledge and practical skills of battery material recycling through the course, laying a foundation for their future career development.

Employees of enterprises engaged in the work related to battery material recycling can improve their professional skills, understand the latest industry trends and improve work efficiency through this course.

Members of the public who are interested in battery material recycling can learn about the importance, technical methods and application prospects of battery material recycling through this course, and enhance their awareness of environmental protection.

5.1.2 Mode of Application

The self-learning course on battery material recycling can be applied in 3 ways: online learning platform, blended learning, corporate training.(Herreid, C. F., & Schiller, N. A. 2013)

The course is released to the online learning platform, and students can access the course content anytime and anywhere for self-learning.

Combine online learning with offline teaching, such as learning theoretical knowledge online and conducting experimental operations and case studies offline.

Apply the courses in corporate training to help corporate employees improve their professional skills and work efficiency.

5.2 Course Evaluation

5.2.1 Course Evaluation Indicators

In order to comprehensively and scientifically evaluate the teaching effect and implementation quality of the self-taught course of battery material recycling, this study constructed a set of evaluation index system with "learning effect, learning experience and learning outcome" as the core dimension.(Kirkpatrick, J. D., & Kirkpatrick, W. K. 2016)The system aims to reflect the actual promotion of the curriculum to the learners' knowledge, ability and development path from multiple perspectives.

First of all, learning effect is the basic dimension of the evaluation system, which mainly focuses on students' understanding and mastery of the course content. Specifically, it includes the following three aspects: First, the knowledge mastery, through online tests, stage assignments and other ways to assess the depth of students' grasp of battery material structure, recycling process and technical principles; The second is the ability to apply skills, through case analysis, project design and other practical links, to examine the ability of students to apply knowledge to practical problems; The third is problem solving ability, which evaluates students' logical thinking, comprehensive analysis and scheme design ability when facing complex tasks.

Secondly, learning experience, as an important perceptual index, reflects students'

subjective satisfaction and participation in the learning process. In terms of curriculum attractiveness, questionnaires and interviews were used to collect students' interest and satisfaction on the structure of teaching content, presentation and quality of resources. In terms of participation in learning activities, the active situation of students in online discussion, question-and-answer interaction, task submission and other aspects can be counted to reflect their active learning enthusiasm. In addition, ease of use of the platform is also a key indicator in the dimension of experience. With the help of system feedback and questionnaires, we can understand students' satisfaction with the interface design, function settings and operation fluency of the Moodle platform.

Finally, learning outcomes focus on the concrete achievements and development progress of students through the course. In terms of achievement, students' results in online tests and final exams can quantify their phased learning results. In terms of project completion, students' practical ability of comprehensive application of curriculum knowledge is assessed through project reports, program design and achievement presentation submitted by students; Further, career orientation is also an important focus of this course. Through follow-up research and interviews, we can find out whether the course has a positive impact on students' internship position selection, research direction or employment development, so as to reflect the long-term value of the course.

5.2.2 Quiz Results Analysis

In order to objectively evaluate the instructional effectiveness of the course, a pilot test was conducted with five student participants. Three separate quizzes were administered throughout the course timeline. Each quiz consisted of four multiple-choice questions, one fill-in-the-blank item, and one open-ended essay question. The aim was to assess students’ understanding of course content, monitor their progress, and identify potential areas for pedagogical improvement. A detailed analysis of the performance results is presented below.

Grade/6.00	Q. 1 /1.00	Q. 2 /1.00	Q. 3 /1.00	Q. 4 /1.00	Q. 5 /1.00	Q. 6 /1.00
0.00	✗ -	✗ -	✗ -	✗ -	✗ -	✗ -
5.00	✓ 1.00	✓ 1.00	✓ 1.00	✓ 1.00	✗ 0.00	✓ 1.00
5.00	✓ 1.00	✓ 1.00	✓ 1.00	✓ 1.00	✗ 0.00	✓ 1.00
4.00	✓ 1.00	✓ 1.00	✗ 0.00	✓ 1.00	✗ 0.00	✓ 1.00
4.00	✓ 1.00	✓ 1.00	✗ 0.00	✓ 1.00	✗ 0.00	✓ 1.00
5.00	✓ 1.00	✓ 1.00	✓ 1.00	✓ 1.00	✗ 0.00	✓ 1.00
3.83 (6)	0.83 (6)	0.83 (6)	0.50 (6)	0.83 (6)	0.00 (6)	0.83 (6)

Figure.9 Result of the Quiz 1

Quiz 1 was mainly about basic knowledge including the classification of battery materials, recycling process flow and ternary material performance indicators. The average score reached was 3.83 points out of 6, and the highest individual score achieved was 5 points. The score distribution appears to show a wide range among the mastery of its content, which could be related to different kinds of background knowledge or engagement during lessons.

The first two items targeted basic comprehension of electrode materials and performance measures and had fairly accurate results across the board for all people involved This shows the effectiveness of the basic module of the course in conveying basic knowledge. In contrast, the fourth question displayed a significantly lower accuracy rate. This item is a conceptual item, allowing open-ended responses from students, which is at odds with the evaluation criteria.

After assessment students' answers revealed that even though wording did not match the expected terminology students' knowledge of concepts was often still there. As this difference shows up in later exams, we might do well to improve how we make our questions and give extra space when giving grades so people can say things differently if they're right.

Grade/6.00	Q. 1 /1.00	Q. 2 /1.00	Q. 3 /1.00	Q. 4 /1.00	Q. 5 /1.00	Q. 6 /1.00
5.00	✔ 1.00	✔ 1.00	✔ 1.00	✖ 0.00	✔ 1.00	✔ 1.00
5.00	✔ 1.00	✔ 1.00	✔ 1.00	✖ 0.00	✔ 1.00	✔ 1.00
6.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00
6.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00
5.00	✔ 1.00	✔ 1.00	✔ 1.00	✖ 0.00	✔ 1.00	✔ 1.00
5.40 (5)	1.00 (5)	1.00 (5)	1.00 (5)	0.40 (5)	1.00 (5)	1.00 (5)

Figure.10 Result of the Quiz 2

In the Quiz 2, the overall performance of the students improved significantly. The average score reached 5.4 points (out of 6 points), which was a marked improvement compared to 3.50 points in the first test. This indicates that as the course progresses, students' understanding of key knowledge points such as battery recycling processes and environmental impacts becomes more solid. Quiz 2 mainly examines students' understanding and application abilities in multiple aspects such as the technical principles and processes, recycling efficiency, and environmental impacts of the three mainstream recycling technologies. Compared with Quiz 1, students not only master the process concepts, It can also accurately correlate its application scenarios with environmental benefits, indicating that the teaching strategy combining course content with reality has a good effect. However, the accuracy rate of the fourth question in quiz2 was relatively low. This might be because there was some ambiguity in the understanding of the content related to bio-metallurgy in the course, resulting in students not fully understanding it. In the future, I will help students clarify the relationship between metallurgical methods, advantages and disadvantages, and environmental impacts through practice with flowcharts or correlation diagrams.

Grade/6.00	Q. 1 /1.00	Q. 2 /1.00	Q. 3 /1.00	Q. 4 /1.00	Q. 5 /1.00	Q. 6 /1.00
3.00	✔ 1.00	✔ 1.00	✔ 1.00	✘ 0.00	✘ 0.00	✘ -
5.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00	✘ 0.00	✔ 1.00
5.80	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00	☑ 0.80
6.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00
5.00	✔ 1.00	✔ 1.00	✔ 1.00	✔ 1.00	✘ 0.00	✔ 1.00
4.96 (5)	1.00 (5)	1.00 (5)	1.00 (5)	0.80 (5)	0.40 (5)	0.76 (5)

Figure.11 Result of the Quiz 3

The third quiz evaluated students' ability to transfer theoretical knowledge into practical applications, covering operational procedures, safety protocols, and cost-efficiency considerations. The average score was 4.96 out of 6, slightly lower than Quiz 2, yet still reflecting a satisfactory level of practical comprehension.

The primary challenge observed in this quiz was again associated with the fourth question, which examined the rationale behind pre-sorting batteries based on chemistry prior to recycling. A subset of responses incorrectly attributed this step to reducing noise or equipment volume, highlighting a gap in the explanation of process-level intent. In response, it is recommended that future course content include targeted instructional segments explaining the strategic value of pre-sorting in improving efficiency, safety, and material yield.

At the end of the testing period, a structured questionnaire was administered to capture learners' subjective feedback across four dimensions: content quality, learning experience, perceived effectiveness, and suggestions for improvement. The combination of quiz performance data and qualitative feedback forms a robust basis for the ongoing refinement of both course content and delivery methodology.

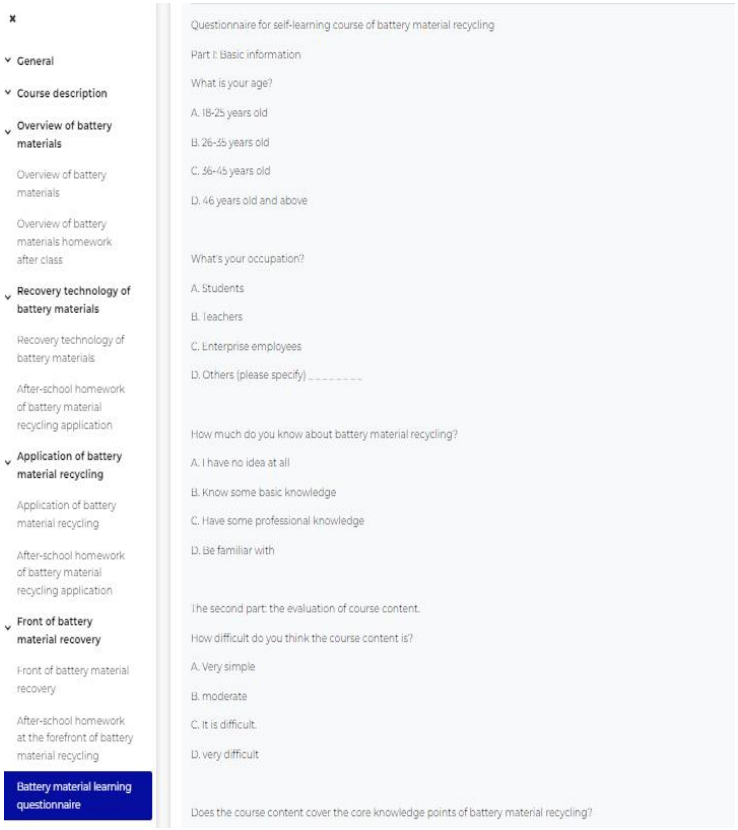

Figure.12 Questionnaire for self-learning course of battery material recycling

6 Summary and Prospect

6.1 Research Summary

Focusing on the theme of design and development of self-learning course on battery material recycling, this study systematically discusses the current situation and development trend of battery material recycling technology, deeply analyzes the design principles and development methods of self-learning course, and successfully develops a set of self-learning course on battery material recycling. The effectiveness and practicability of the course were verified through course application and evaluation. The following are the main results and contributions of this research:

6.1.1 Research Achievements

1. Overview of battery material recycling technology: This research systematically sorted out the technical routes, process flow and development trend of battery material recycling, which provided theoretical basis and technical support for the design of course content.

2. Principles of self-learning course design: This study proposes the principles of learner-centeredness, modularization design, interactivity design and evaluation system design, which provide a guiding framework for the development of self-learning courses.

3. Course content development: This study develops course content covering the basics of battery material recycling, technical methods, application cases and cutting-edge developments, including text, video, animation and cases in various forms.

4. Course platform development: This study designs and develops a self-study course platform with perfect functions and friendly interface, which supports online learning, interactive communication and evaluation feedback.

5. Course application and evaluation: This study applies the course to actual teaching and comprehensively evaluates the effect of the course through questionnaires, interviews and data analysis to verify the effectiveness and practicality of the course.

6.1.2 Research Contributions

1. Theoretical contribution: This study enriches the theoretical system of self-learning course design and provides new ideas and methods for online education in the field of battery material recycling.

2. Practical contribution: The self-learning course on battery material recycling developed in this study provides a convenient learning pathway for students of related majors, employees of enterprises and the public, and helps to improve the professional knowledge and skills of battery material recycling.

3. Social contribution: By promoting the knowledge and technology of battery material recycling, this study promotes the recycling of resources and the sustainable development of the environment, which is of great social significance.

6.2 Research Prospects

Although this study has achieved certain results, there are still some shortcomings that need to be further improved and refined in future research. The following is the future outlook of this study:

6.2.1 Optimizing Course Content

1. Increase the content of cutting-edge technology: With the continuous development of battery material recycling technology, more cutting-edge technology content can be added in the future, such as new recycling process and intelligent recycling equipment.

2. Enrich case resources: In the future, more practical cases can be collected, especially successful cases of battery material recycling projects at home and abroad, to help students better understand and apply what they have learned.

3. Enhance practical aspects: more practical aspects can be added in the future, such as virtual experiments, simulation operations, etc., to help students combine theoretical knowledge with practical skills.

6.2.2 Upgrading Course Platform

1. Enhance platform performance: In the future, the performance of the course platform can be further optimized to improve the page loading speed and response speed, so as to enhance the user experience.

2. Enhance interactive functions: In the future, more interactive functions can be added, such as online discussions, real-time Q&A, study groups, etc., to enhance the interaction and communication among students.

3. Introduce artificial intelligence technology: In the future, artificial intelligence technology can be introduced, such as intelligent recommendation, personalized learning path, etc., to provide students with a more personalized learning experience.(Holmes, W., Bialik, M., & Fadel, C. 2019)

6.2.3 Promotion the application of the course

1. Expanding the scope of application: In the future, the course can be promoted to more colleges and universities, enterprises and social organizations to expand the scope of application and influence of the course.

2. International cooperation: In the future, we can cooperate with internationally renowned universities and research institutes to develop an internationalized self-learning course on battery material recycling and promote international exchange and cooperation.

3. Establish a course certification system: In the future, a course certification system can be established to issue certification certificates to students who have completed the course, so as to enhance the authority and recognition of the course.

6.2.4 Research Field Expansion

1. Interdisciplinary Research: Moving forward, interdisciplinary research can be pursued by integrating fields such as materials science, environmental engineering, and information technology, aiming to explore new technologies and methods for battery material recycling.

2. Policy Research: Future research can focus on the policies surrounding battery material recycling, offering theoretical foundations and practical recommendations to guide the government in developing relevant policies.

3. Social Impact Assessment: In the future, social impact assessments of battery material recycling can be conducted to evaluate its effects on resource recovery, environmental protection, and economic growth.

6.3 Conclusion

The design and development of a self-learning course on battery material recycling represents a comprehensive and interdisciplinary endeavor that integrates educational technology with sustainable engineering practices. This study has successfully constructed a structured and modular online learning system grounded in current battery recycling technologies, offering a novel pedagogical approach for technical education in the environmental and energy sectors.

The course design emphasizes learner-centered progression, multimodal content delivery, and practical relevance, thereby contributing both theoretically and methodologically to the development of domain-specific online education. Through empirical testing and learner feedback, the system has demonstrated initial effectiveness in enhancing knowledge acquisition and applied competencies.

Looking ahead, improvements next will have adaptive learning algorithms for personalized content paths with AI driven feedback systems for engagement, and international collaboration through a multilingual delivery and joint certification. To amplify the reach, elevate its influence globally about sustainable battery recycling, and make education’s renewal even more in tune with what the environment must have.

References

Baum, Z. (2022) A greener future: Lithium-ion batteries and hydrogen fuel cells. Cited 5June 2025. https://www.cas.org/resources/cas-insights/lithium-batteries-hydrogen-fuel-cells.

Chen, J., Zhang, R. and Li, J. (2024) A new method to recycle Li-ion batteries with lasermaterials processing technology. Sustainable Materials and Technologies, 41, e01095. https://doi.org/10.1016/j.susmat.2024.e01095.

Chen, X., Ma, H., Luo, C. and Zhou, T. (2017). Recovery of valuable metals from waste cathode materials of spent lithium-ion batteries using mild phosphoric acid. Journal of Hazardous Materials, 326, 77–86. https://doi.org/10.1016/j.jhazmat.2016.12.021.

Fan, E., et al. (2020) Sustainable recycling technology for Li-ion batteries and beyond: Challenges and future prospects. Chemical Reviews, 120(14), pp.7020–7063. https://pubs.acs.org/doi/10.1021/acs.chemrev.9b00535.

Harper, G., et al. (2019) Recycling lithium-ion batteries from electric vehicles. Nature, 575(7781), pp.75–86. https://doi.org/10.1038/s41586-019-1682-5.

Herreid, C.F. and Schiller, N.A. (2013) Case studies and the flipped classroom. Journal of College Science Teaching, 42(5), pp.62–66. https://www.jstor.org/stable/43631584.

Holmes, W., Bialik, M. and Fadel, C. (2019) Artificial intelligence in education: Promises and implications for teaching and learning. Center for Curriculum Redesign. Cited 5 June 2025. https://curriculumredesign.org/wp-content/uploads/AIED-Book-Excerpt-CCR.pdf.

International Energy Agency (IEA) (2022) Global EV outlook 2022: Securing supplies for an electric future. Cited 5 June 2025. https://www.iea.org/reports/global-ev-outlook-2022.

Jensen, L. and Konradsen, F. (2018) A review of the use of virtual reality head-mounted displays in education and training. Education and Information Technologies, 23(4), pp.1515–1529. https://doi.org/10.1007/s10639-017-9676-0.

Kirkpatrick, J.D. and Kirkpatrick, W.K. (2016) Kirkpatrick's four levels of training evaluation. ATD Press. Cited 5 June 2025. https://www.amazon.com/Kirkpatricks-Four-Levels-Training-Evaluation/dp/1607280086.

Kolodner, J.L. (1993) Case-based reasoning. Morgan Kaufmann. Cited 5 June 2025. https://www.sciencedirect.com/book/9781558602373/case-based-reasoning?via=ihub.

Makuza, B., Tian, Q., Wang, K., Liu, Y., Wu, Y. and Lv, Y. (2021). Pyrometallurgical options for recycling spent lithium-ion batteries: A comprehensive review. Journal of Power Sources,

491, 229622. https://doi.org/10.1016/j.jpowsour.2021.229622.

Mayyas, A., Steward, D. and Mann, M. (2019) The case for recycling: Overview and challenges in the material supply chain for automotive Li-ion batteries. Sustainable Materials and Technologies, 19, e00087. https://doi.org/10.1016/j.susmat.2018.e00087.

Mishra, D., Kim, D.J., Ralph, D.E., Ahn, J.G. and Rhee, Y.H. (2008) Bioleaching of metals from spent lithium-ion secondary batteries using Acidithiobacillus ferrooxidans. Waste Management, 28(2), pp.333–337. https://doi.org/10.1016/j.wasman.2007.01.010.

Radianti, J., Majchrzak, T.A., Fromm, J. and Wohlgenannt, I. (2020) A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Computers and Education, 147, 103778. https://doi.org/10.1016/j.compedu.2019.103778.

Sangrà, A., Vlachopoulos, D. and Cabrera, N. (2012) Building an inclusive definition of e-learning: An approach to the conceptual framework. International Review of Research in Open and Distributed Learning, 13(2), pp.145–159. https://doi.org/10.19173/irrodl.v13i2.1161.

United Nations Environment Programme (UNEP) (2021) Used lead acid batteries (ULAB). Cited.5June.2025.
https://www.unep.org/topics/chemicals-and-pollution-action/pollution-and-health/heavy-metals/used-lead-acid-batteries.

Wang, X., Gaustad, G. and Babbitt, C.W. (2016) Targeting high value metals in lithium-ion battery recycling via shredding and size-based separation. Waste Management, 51, pp.204–212. https://doi.org/10.1016/j.wasman.2015.10.026.