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Exploration and Practice of Teaching Reform in Programmable Controller Technology Courses

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Abstract The intelligent upgrading of manufacturing has placed higher demands on programmable logic controller (PLC) technical personnel. This paper proposes an industrial case-driven teaching model for PLC technology courses. Based on knowledge graphs and Petri nets, an aggregation model for process knowledge discovery is constructed to achieve analogy transfer for multi-domain engineering problems. A hierarchical embedding collaborative recommendation model (HECR) is designed, utilizing multi-scale graph convolutions, residual connections, and LightGCN to optimize the matching of engineering problems and teaching resources. The model's loss function stabilizes around 0.0512 as the number of recommendation method learning iterations increases. When the resource hierarchy is set to 10 levels, the model's two metric values reach their highest values of 0.629 and 0.686. Students' satisfaction with the reformed teaching methods exceeded 0.830 across all four emotional evaluation themes.

Index Terms programmable controller, knowledge aggregation model, teaching reform, hierarchical embedding, HECR

I. Introduction

Programmable Logic Controller (PLC) Technology is a specialized technical course in engineering disciplines, serving as a core component of the curriculum and talent development programs for electrical engineering and mechatronics engineering programs [1]. Under the guidance of the new engineering education philosophy, course instruction should transcend traditional disciplinary boundaries to promote interdisciplinary integration among computer science and technology, electronics and information technology, control theory, and other fields, thereby cultivating composite talents with comprehensive competencies and innovative capabilities [2]-[5]. Therefore, as a core course for automation and related majors, the teaching reform of the PLC Technology and Application course is particularly important.

Currently, the PLC technology course faces numerous issues in both theoretical instruction and practical skill development. On one hand, the course curriculum is not closely aligned with the industrialization of modern manufacturing [6]. The content arrangement of existing PLC technology course textbooks lags behind current industrial production needs, making it difficult to achieve close alignment with modern manufacturing industrialization [7], [8]. Even when enterprise practice components are included, they remain at the observation stage and do not delve into industrial production, failing to cultivate students' practical production capabilities [9], [10]. On the other hand, existing teaching philosophies and models do not truly reflect the characteristics of education emphasizing practice, multiple perspectives, and comprehensive development [11]. For example, there is a lack of PLC engineering application case studies in the arrangement of teaching content, and assessment methods cannot comprehensively evaluate students' integrated theoretical and practical abilities [12], [13]. The limitations of teaching models hinder the improvement of students' independent design capabilities, severely restricting the cultivation of their practical application abilities and leading to a disconnect between theory and practice [14]-[16]. Therefore, it is imperative to undertake teaching reforms to cultivate high-quality engineering and technical talent with a solid theoretical foundation, outstanding practical abilities, and innovative thinking, thereby providing a robust talent pool to support the rapid development of the industrial automation field.

Traditional PLC teaching methods and tools primarily rely on combining classroom lectures using PowerPoint presentations with experimental verification. While this approach can help students grasp the basic principles and programming methods of PLCs to some extent, it fails to cultivate students' innovative and practical abilities. To address this, scholars have proposed integrating existing teaching models with PLC course content to explore practical pathways for educational reform. Yu, G., and Ju, E. developed a multi-level PLC course innovation and practical training system based on outcome-oriented principles, with the core objective of creating student value, to cultivate the core competencies and core competencies of new engineering talent in an engineering context [17]. Wenfeng, Z, and others introduced a blended online and offline teaching model into electrical control technology courses, integrating online case-based teaching with offline experimental courses to effectively enhance students' practical skills [18]. Yan, W explored the advantages of blended teaching methods in PLC technology course instruction, which can combine online and offline teaching resources to conduct theory-practice integrated teaching activities, playing a significant role in cultivating and enhancing students' programming design capabilities [19]. Zaher, A. A., et al. introduced the STEAMeD teaching model applicable to engineering majors, which combines educational attributes with course content to clearly describe learning outcomes, thereby effectively promoting the quality of students' learning processes [20].

In addition to optimizing educational models, teaching technologies must also be reformed to improve teaching effectiveness and students' interest in learning. To this end, some scholars have kept a close eye on industry trends and technological frontiers, proposing scientifically reasonable teaching auxiliary technologies. Shi, X. M., et al. introduced virtual reality technology into the experimental projects of PLC course teaching to strengthen the integration of theoretical and practical teaching. They continuously improved the teaching design through course feedback, significantly enhancing students initiative and teaching effectiveness [21]. Wang, S., et al. designed an undergraduate experimental teaching platform as an auxiliary teaching tool, applying it to electrical control courses to improve students' learning efficiency in courses that combine theory and practice [22]. Chengwei, Z, and others proposed a course teaching reform strategy based on the MATLAB simulation platform, which can optimize teaching content and assessment methods, providing strong support for electrical engineering course teaching [23]. Pratama, H, and others developed a practical teaching auxiliary tool based on multimedia devices, which provides effective conditions for the implementation of PLC course teaching design, helping teachers better conduct theoretical and practical teaching, thereby enhancing teaching effectiveness [24].

In this paper, we design an industrial case base based on the principle of problem orientation, construct a dual-driven model of knowledge aggregation and collaborative recommendation, and strengthen the teaching level of PLC programming through a stepped task chain. A process knowledge discovery framework is established, and a problem space semantic network is constructed by utilizing knowledge mapping to quantify the cross-case analogical potential of engineering problems in combination with the Analogical Potential Index (APVI) index. Develop a hierarchical embedding model (HECR) to fuse multi-scale teaching resource features through graph coarsening strategy, and design a lightweight graph convolution network (LightGCN) to solve the oversmoothing problem in resource recommendation. Calculate the loss function of recommendation methods to predict the degree of user preference for resources.

II. Optimization of programmable control technology course teaching based on industrial cases

II. A. Industrial Case and Teaching Process Design

II. A. 1) Case design ideas

The key core of industrial case design is closely related to practical needs and emphasizes the development of students' practical skills. The case design should be centered on solving the problems that are more difficult for students to solve in the theoretical courses, especially the complexity related to the design, debugging and troubleshooting of programmable logic controller (PLC) systems and other practical operations. It is important to take into account the students' knowledge accumulation and skill level, so that the difficulty of the case gradually upward. Students can take the first step from basic tasks to more complex control system design and optimization skills. The design of the case should start with a problem-oriented approach and set up challenging problem situations to stimulate students' interest in learning and exploration. Problem situations should be both real and practical value, so that students respond to the problem to strengthen the degree of understanding of PLC knowledge, to create its analysis of the problem and the ability to overcome the problem; should be advocated to work together as a team, reflecting the core elements of teamwork in the design. Students can cooperate in the team division of labor, together to explore and overcome the technical difficulties in the case, which will greatly enhance the students' cooperation skills, improve their communication skills and teamwork level, and develop the ability to deal with the problem with collective wisdom. Case design needs to have a certain degree of flexibility, the design should take into account the learning basis and needs of different students, to give a differentiated solution or implementation of the task extension, to ensure that each student in the actual operation of their own solutions can be found, so as to cultivate students to randomly cope with the ability to solve practical engineering difficulties. Figure 1 shows the case design process.

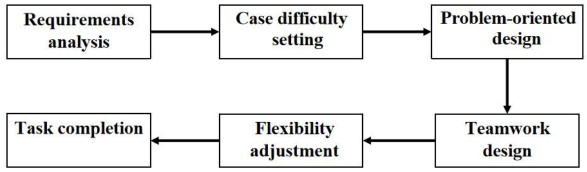

Figure 1: Case design process

II. A. 2) Teaching process design

Teaching process design is the core component of the industrial case-driven teaching model, which is intended to make every stage of teaching activities closely aligned with the course objectives and student learning needs. The first step is to clarify the teaching objectives, which is the beginning of the process design, each teaching activity should be centered on the goal. The purpose of the course is to enable students to master the principles of PLC system design and its application in real engineering, teachers need to set clear learning tasks and knowledge to ensure that students use case studies to deal with problems in real engineering. In the case introduction and task assignment stage, the teacher selects an industrial case closely linked to the course objectives to stimulate students' interest and drive them to explore the initiation of their own. When assigning tasks, students can be divided into groups, each group will take on a part of the case, driving students to conduct independent research and discussion. In the case analysis, discussion of this stage, students according to the task requirements of the case to do in-depth analysis, the teacher to play a role in guiding the function, to ensure that students understand the technical difficulties in the case, and can rely on the theory of learning to put forward a response plan. In the experimental operation and program practice period, students to the theoretical analysis and practical operation of the integration of PLC equipment or simulation software to implement simulation experiments to determine the feasibility of the solution.

II. B.Knowledge aggregation model construction for process knowledge discovery

"Process knowledge" is the steps needed to solve engineering optimization problems in teaching, such as selection, crossover, and mutation needed to use genetic algorithms. In order to support the method innovation of engineering optimization problems, a knowledge aggregation model for process knowledge discovery is proposed based on knowledge graph, Petri net and analogy to achieve process knowledge discovery. Figure 2 shows the knowledge aggregation model for process knowledge discovery.

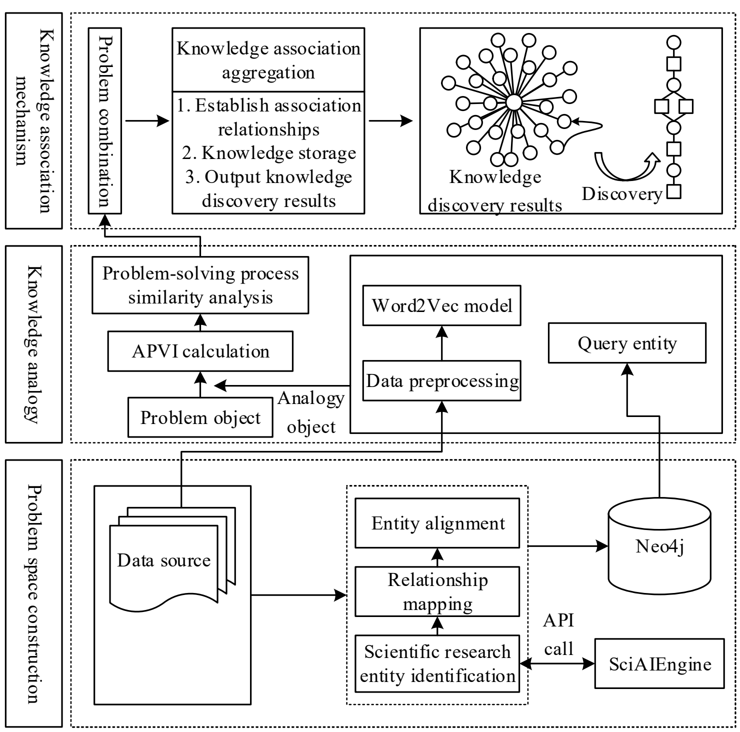

Figure 2: Knowledge aggregation model for process knowledge discovery

II. B. 1) Constructing the problem space

The knowledge graph is used to describe the semantic relationships between entities in the problem space, and the construction process includes two parts: research entity identification and knowledge graph construction.

For research entity recognition, the Chinese research entity recognition module in Sci AIEngine platform is used to extract the two entities of “research method” and “research question” in the abstract. The specific process is to call the API interface in Sci AIEngine platform. The knowledge graph is constructed in a bottom-up manner, and the process is as follows: 1) extract research entities from the abstracts based on Sci AIEngine; 2) remove useless, duplicated, and erroneous entities, etc.; 3) build a relational mapping for all the entities based on the predefined entities and their relationships; and 4) store them in the Neo4j graph database after entity alignment.

II. B. 2) Knowledge analogies

Select a research problem as the “problem object”, and implement the analogy as follows: 1) Filter similar research problems in other problem spaces as the “analogy object” based on the word vector model. 2) Identify problem combinations with knowledge transfer opportunities based on the APVI formula. 3) Analyze the similarity of problem combinations in terms of solution process using Petri net modeling process knowledge. 4) Analyze the similarity of problem combinations in terms of solution process using the Petri net modeling process knowledge. 3) Use Petri net to model process knowledge and analyze the similarity of problem combinations in terms of solution process.

1) Identification of knowledge transfer opportunities

In order to assess the knowledge migration opportunity between the “problem object” and each “analog”, i.e., the potential of the knowledge in the problem space of the analog object to be transferred to the problem space of the problem object, the Analog Potential Index (APVI) is defined. It is assumed that the analogies are based on groups of methods that co-occur in the two problem spaces, that the non-co-occurring methods are speculative sources, and that the process knowledge used in a piece of literature is one group.

Definition 1: Analogical Feasibility Intensity (AFI)

It refers to the strength of analogical speculation that can be made between two research problems corresponding to their solutions. Obviously, AFI is positively related to the number of analogical bases and speculative sources, the more the number of analogical bases between P_1 and P_2, the more adequate the analogy; at the same time, if the number of speculative sources is more, it represents more opportunities to speculate about the unknown relationship, then AFI for the existence of analogical bases for the research problem between P_1 and P_2 can be expressed as equation (1):

$$AFI = \frac{(m+1)^2 \times n}{|P_1| + |P_2| - m} + \frac{|P_2|}{2} \tag{1}$$

In equation (1), m is the number of analogical bases; n is the number of speculative sources; P_1 is the problem object, $|P_1|$ is the number of groups of P_1; P_2 is from the analogical object, and $|P_2|$ is the number of groups of P_2.

Definition 2: Analogical Potential Value Index (APVI), a measure of the likelihood that analogical speculation can be made for two similar research problems with their corresponding solutions, with a larger APVI representing a greater opportunity for knowledge transfer. APVI is related to the similarity between the research problems and the strength of the feasibility of the analogies, and it is considered that both are equally important to the impact of the APVI, and therefore they are given a weighting of 0.50 respectively; so that $APVI$ between two similar research questions P_1 and P_2 is defined as Equation (2):

$$APVI = 0.50 \times Sim(P_1, P_2) + 0.50 \times AFI \tag{2}$$

In Eq. (2), $Sim(P_1, P_2)$ denotes the cosine similarity between problems P_1 and P_2, and AFI is denoted as the analogous feasibility intensity between P_1 and P_2.

2) Similarity analysis of problem solving process

Definition 3: Petri net A Petri net is represented by a triple $N = (P, T, F)$ where: P is the finite set of all libraries, T is the finite set of variations, and there exists $P \cap T = \varnothing$, $F \subseteq (P \times T) \cup (T \times P)$ is the set of directed arcs, which represents the flow relationship (in the text, only variation nodes are used to describe the process since libraries are not of practical significance in the modeling process).

Another key to analogical discovery that can be made between different problems is whether two problems using similar or comparable solution methods have a high degree of similarity in the solution process. Therefore, Petri nets are used to unify the knowledge of the modeling process, to understand the whole process intuitively, and to analyze and determine the similarity between the two in the solution process.

II. C. Collaborative recommendation model based on hierarchical embedding

II. C. 1) Overview of the model

In order to facilitate students and teachers to effectively select appropriate industrial case problems and related resources for learning and research, this paper proposes a collaborative recommendation model HECR based on hierarchical embedding. Figure 3 shows the structure of the model. The model generates a multi-scale collaborative graph of knowledge of teaching resources based on coarsening strategy for enhancing global relationship learning and information dissemination among nodes when entity features are represented, and enhances the discriminative ability of collaborative filtering paradigm based on graph representation learning by combining different scales of sensory wilds in order to improve the model's ability to characterize the nodes, and effectively mitigates the problem of oversmoothing of the node representations of the users and the projects. The model also optimizes the neighborhood relationship modeling of traditional graph collaborative filtering methods, and finally mines self-supervised information from knowledge graph nodes through multi-view encoding.

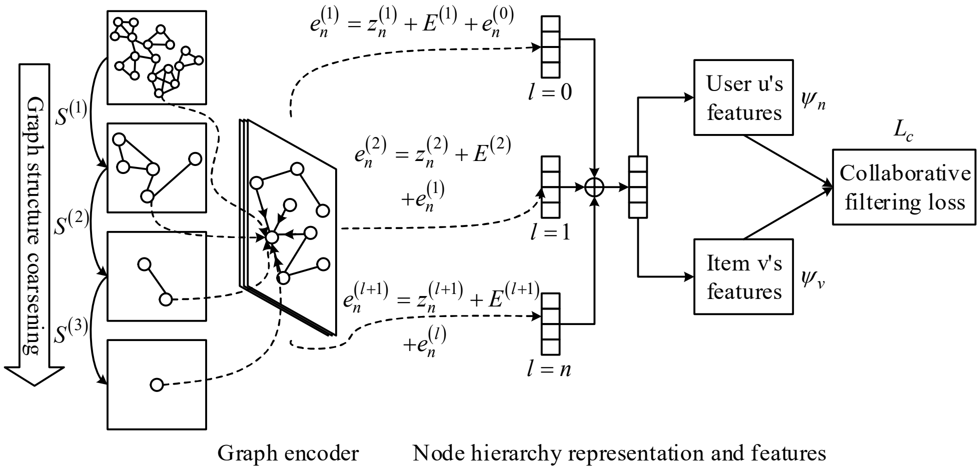

Figure 3: Structure of the HECR model

Specifically, the graph coarsening technique is first used to aggregate multiple nodes into a cluster node to generate a series of coarsened subgraphs for the input teaching resource knowledge co-graph to describe the multi-scale structural information and global dependencies. Second, graph convolution is utilized as an encoder for information transfer and aggregation on the knowledge co-graph as a way to capture local synergistic similarities between user features and item features. In addition, the computational results of neighboring layers are connected using residuals during knowledge aggregation to better fit the data by increasing the model complexity to mitigate the oversmoothing problem. Then, by overlaying multi-scale hierarchical information, local representations of nodes can effectively join global dependencies to capture the global collaborative effect of graph encoder-based for better feature representation. Finally, the local representations of the nodes and the multi-scale global representations are aggregated into a vector and fed into the collaborative filtering network for the interaction prediction of user items, and the pairwise loss is used to calculate the degree of deviation of the prediction results and iterative training can make the model parameters return to an accurate description of the user's interests and preferences.

II. C. 2) Design of LightGCN-based local feature coding module

Based on the basic paradigm of collaborative filtering algorithms, the HECR model first assigns implicit embedding vectors to each user and item in the knowledge collaborative graph in order to learn the feature representations of that node, and denotes the embedding matrix of users as $E^{(u)} \in \mathbb{R}^{I\times d}$ and the embedding matrix of items as $E^{(I)} \in \mathbb{R}^{J\times d}$, where $e_i^{(u)} \in \mathbb{R}^d$ and $e_j^{(v)} \in \mathbb{R}^d$ denote the feature representations of user u_i and item v_j, respectively, and sets the dimensionality of the individual features to d, I, and J to denote the number of users and items in the input, respectively. Based on this base representation, HECR uses a superimposed graph convolutional network to learn users' neighborhood relationships. First, a LightGCN-based model is used as an encoder to capture the local features of the graph with the message passing as shown in Equation (3):

$$z_n = \sigma\left(\overline{Y}_{n,*} \cdot E\right) \tag{3}$$

where z is the node feature representation obtained from the neighborhood aggregated messages, and $z_n \in \mathbb{R}^d$ indicates that the central node of the message aggregation is node n. σ denotes the nonlinear activation function LeakyReLU, which is used to take into account the nonlinear feature transformations of the model and to mitigate the gradient vanishing problem during backpropagation. $\overline{Y} \in \mathbb{R}^{I \times J}$ denotes the normalized adjacency matrix derived from the user-item interaction matrix Y, which is obtained based on the variation of the Laplace matrix $L = D - A$, and is computed as shown in Equation (4):

$$\begin{gathered} \overline{Y} = I - D_u^{-\frac{1}{2}} \cdot Y \cdot D_v^{-\frac{1}{2}} \\ \overline{Y}_{ij} = \frac{Y_{ij}}{\sqrt{|N_i| \cdot |N_j|}} \end{gathered} \tag{4}$$

where $D_u \in \mathbb{R}^{I \times I}$, $D_v \in \mathbb{R}^{J \times J}$ denote the degree diagonal matrices of the set of user and project nodes, $\overline{Y}_{I,j}$ is the basic element in $\overline{Y}$, and $|N_i|$ and $|N_j|$ denote the number of neighbors of the user node u_I and project node v_j, respectively.

Subsequently, the feature representations e_n of the users and projects d are re-encoded for generating contextualized feature representations. Since the representation of the central node needs to aggregate local neighbor node information, multiple embedded propagation layers need to be stacked for learning higher-order neighbor relationships of the nodes. Let $e_n^{(l)}$ denote the embedding vector in layer l of LightGCN using node n, where l denotes the l th information transmission. The propagation process from layer l to $(l+1)$ can be formally defined as equation (5):

$$e_n^{(l+1)} = z_n^{(l)} + e_n^{(l)} \tag{5}$$

Since the node representations of the graph neural network are propagated to neighboring nodes along the connectivity in the graph during each iteration, neighborhood smoothing of the node feature representations is achieved based on the original interaction graph. In addition, in the process of message aggregation across convolutional layers, the nonlinear activations of the input source and target node features are aggregated using residual connections, which alleviates the over-smoothing problem caused by the excessive depth of graph neural network layers by emphasizing the semantics of the central node.

II. C. 3) Node Representation Fusion and Recommendation Loss Function Design

In order to make the feature representation of the target node with both local feature encoding of the graph and global synergistic relationship, the local feature encoding generated by LightGCN in the knowledge synergistic graph and the multiscale node cluster feature representation in the coarsened graph are superimposed, and the feature representation e_n^{l+1} obtained from the aggregation at the $(l+1)$ st layer is described as shown in Eq. (6).

$$e_n^{(l+1)} = z_n^{(l)} + E^{(l+1)} + e_n^{(l)} \tag{6}$$

where $z_n^{(l)}$ is the feature representation obtained by aggregating the local neighborhood information of node n in that layer, $E^{(l+1)}$ is the global feature representation of the node cluster to which node n belongs in layer $(l+1)$, and aggregates the previous layer's representation through residual linkage $e_n^{(l)}$. Then, HECR obtains the feature representations of the user and the project iteratively through multiple coarsening operations and accumulates them, specifically, ψ_u and ψ_v denote the user node u and the project node v, respectively, in the knowledge collaborative graph Multi-scale fusion representations, whose embedding vectors are represented as shown in Eq. (7):

$$\psi_u = \sum\nolimits_{l=0}^{L} e_u^{(l)}, \psi_v = \sum\nolimits_{l=0}^{L} e_v^{(l)} \tag{7}$$

Subsequently, based on the idea of collaborative filtering, preference prediction for user and item combinations is performed using the inner product operator, expressed as shown in Equation (8):

$$P_{u,v} = \psi_u^T \cdot \psi_v \tag{8}$$

The model parameters are trained and optimized using the Hinge pairwise loss function L_c, represented as shown in Equation (9):

$$L_c = \sum_{u=1}^{N} \sum_{i=1}^{I} \max\left(0, 1 - P_{u,p_i} + P_{u,n_i}\right) \tag{9}$$

where p_i is a positive sample and n_i is a negative sample, for each user u sampling I positive and negative samples for learning. Finally, the encoding of node features in the knowledge synergy graph in CKGR is replaced using the method of multi-scale fusion of features to obtain a multi-task description to obtain the loss function of the entire recommendation method, described as shown in Eq. (10):

$$L = L_c + \lambda_1 L_s + \lambda_2 \|\Theta\|_2^2 \tag{10}$$

III. Teaching practice of programmable control technology course based on industrial cases

III. A. Model performance test

III. A. 1) Resource Recommendation Capability Analysis of the HECR Model

To evaluate the resource recommendation performance and primary functional modules of the HECR model, two datasets were selected as test subjects, and multi-model recommendation effectiveness comparison experiments and ablation experiments were conducted. Table 1 shows the resource recommendation effectiveness of six similar resource recommendation models. On the DIGINETICA dataset, the HECR model achieved the highest values across all three categories and six metrics, reaching 0.321, 0.484, 0.189, 0.232, 0.329, and 0.337; On the YOOCHOOSE dataset, the HECR model also achieved the highest values across all metrics, reaching 0.604, 0.733, 0.455, 0.488, 0.527, and 0.547. This indicates that the HECR model demonstrates the best recommendation performance in resource recommendation across both datasets.

Table 1: The resource recommendation effects of the 6 models

DIGINETICA						
	Hit@6	Hit@10	Mrr@6	Mrr@10	Ndcg@6	Ndcg@10
KGAT	0.222	0.381	0.173	0.185	0.201	0.249
GRU4Rec	0.225	0.374	0.171	0.181	0.202	0.243
VBPR	0.231	0.392	0.176	0.187	0.206	0.252
Wide &Deep	0.227	0.375	0.177	0.186	0.207	0.246
SASRec	0.214	0.413	0.171	0.191	0.205	0.254
HECR	0.321	0.484	0.189	0.232	0.329	0.337
YOOCHOOSE						
	Hit@6	Hit@10	Mrr@6	Mrr@10	Ndcg@6	Ndcg@10
KGAT	0.491	0.634	0.356	0.381	0.423	0.445
GRU4Rec	0.515	0.647	0.371	0.396	0.446	0.464
VBPR	0.509	0.644	0.354	0.383	0.424	0.451
Wide &Deep	0.511	0.641	0.367	0.392	0.438	0.461
SASRec	0.537	0.648	0.377	0.402	0.462	0.478
HECR	0.604	0.733	0.455	0.488	0.527	0.547

III. A. 2) Ablation experiment results and analysis

Table 2 shows the results of ablation experiments for the HECR model. This subsection compares the performance of HECR under different settings. Specifically, the HECR(without Multiscale Graph Coarsening) version removes the multiscale graph coarsening; the HECR(without Residual connection) version removes the residual connection mechanism; and the HECR(without LightGCN) version removes the LightGCN local feature encoding module.The HECR(without Multiscale Graph Coarsening) version has the smallest values of the 6 metrics in the 2 datasets, indicating that multiscale graph coarsening contributes the most to global feature fusion, and this module needs to be paid special attention to during the model construction process. The 2nd most influential is the mechanism of residual linking, and the least influential is the LightGCN local feature encoding module.The resource recommendation performance of the HECR model fused by the 3 modules is always the best.

Table 2: The ablation experiment results of the HECR model

DIGINETICA						
	Hit@6	Hit@10	Mrr@6	Mrr@10	Ndcg@6	Ndcg@10
HECR (without Multiscale Graph Coarsening)	0.105	0.184	0.100	0.127	0.125	0.163
HECR (without Residual connection)	0.167	0.252	0.124	0.149	0.152	0.184
HECR (without LightGCN)	0.200	0.371	0.138	0.157	0.178	0.201
HECR	0.221	0.364	0.169	0.182	0.199	0.237
YOOCHOOSE						
	Hit@6	Hit@10	Mrr@6	Mrr@10	Ndcg@6	Ndcg@10
HECR (without Multiscale Graph Coarsening)	0.276	0.299	0.105	0.121	0.204	0.267
HECR (without Residual connection)	0.319	0.378	0.249	0.257	0.317	0.315
HECR (without LightGCN)	0.452	0.481	0.298	0.306	0.396	0.414
HECR	0.504	0.633	0.355	0.388	0.427	0.447

IV. Comparison of Resource Tier Determination and Effectiveness Based on HECR Modeling

IV. A. 1) Resource level clustering results

Figure 4 shows the hierarchical structure of course resources based on engineering cases. The resources related to the programmable controller technology course are categorized into 10 tiers, and through the structure of each tier, it is easier to call the resources of each tier and generate suitable recommended solutions for the students when they retrieve certain types of resources.

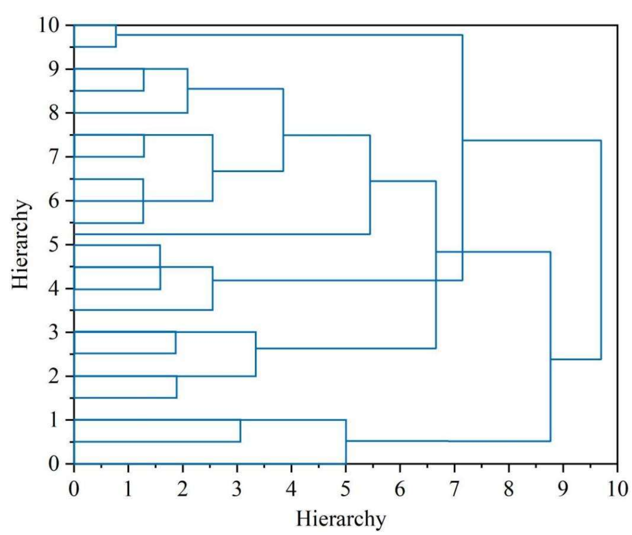

Figure 4: Course resource hierarchical structure based on engineering cases

IV. A. 2) Analysis of model loss function changes

Figure 5 shows the change of loss function for different recommendation schemes. From the figure, it can be seen that within the first 3573 recommendation schemes, the model is in the initial learning stage, so the loss value decreases more, with the deeper learning of the model, starting from the 6943th recommendation scheme, the loss value tends to stabilize, and finally converges, with a convergence value of about 0.0512. The trained model can generate recommendation schemes with small loss values, which can well predict the students' learning resource needs.

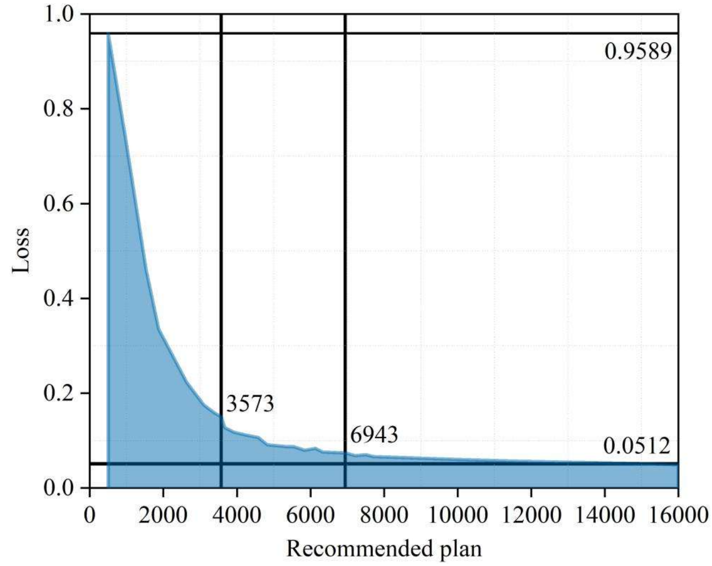

Figure 5: The changes in loss functions for different recommendation schemes

IV. A. 3) Comparison of model performance with different number of layers

Course resource layers relate to the accuracy and efficiency of the recommendation method, so the optimal number of layers to build needs to be determined. The number of layers is set to 10 and 15, and multiple models are selected for comparison experiments to determine the model resource recommendation performance under different layers, so as to determine the optimal value of the number of layers setting. Table 3 shows the resource recommendation performance of the model when H=10. Table 4 is the resource recommendation effect of the model when H=15. When the layer is 10, the HR metric of HECR is up to 0.629 and the NDCG metric is up to 0.686, which is higher than the HR and NDCG metric values when the layer is 15. Meanwhile, the HECR model has higher indicator values than the comparison model when the number of layers is 10 and 15. Therefore, in this paper, setting the number of resource layers to 10 can provide the best resource recommendation program for students.

Table 3: The resource recommendation effect of the model of H=10

Model	HR	NDCG
KGAT	0.524	0.471
GRU4Rec	0.537	0.489
VBPR	0.562	0.533
Wide &Deep	0.563	0.565
SASRec	0.592	0.623
HECR	0.629	0.686

Table 4: The resource recommendation effect of the model of H=15

Model	HR	NDCG
KGAT	0.503	0.293
GRU4Rec	0.512	0.305
VBPR	0.535	0.347
Wide &Deep	0.538	0.381
SASRec	0.567	0.416
HECR	0.604	0.498

IV. B. Analysis of Teaching Satisfaction

IV. B. 1) Statistics on the results of sentiment analysis by theme

The teaching reform methodology in this paper is applied to a programmable controller technology course in a university majoring in electronic engineering, using the developed model to assist the students in the program. The teaching experiment lasted for one academic year, and at the end of the experiment, a questionnaire was chosen to collect feedback from 500 students on the teaching methods of the course. 500 questionnaires were distributed, and 500 questionnaires were valid, with a validity rate of 100%. This section focuses on quantifying the students' comments, and the text-based data will be scored by the dictionary to get the numerical data. The lexicon based on which the textual sentiment analysis in this paper is based is the Bosson Sentiment Dictionary, which encompasses many online words and is applicable to the current student questionnaire comments. In this dictionary, each word occupies a separate line with a corresponding sentiment score. Positive numbers represent positive words and negative numbers represent negative words, and the greater the absolute value, the stronger the degree. In this paper, sentiment scores greater than 0.00 are judged as positive sentiment tendencies, sentiment scores less than 0.00 are judged as negative sentiment tendencies, and sentiment scores equal to 0.00 are judged as neutral sentiment tendencies. Using text sentiment analysis can calculate the probability value of each comment belonging to a certain topic, this paper chooses the probability value of the largest as the topic of the comment. The type to which the topic belongs is added to the results of the sentiment analysis, and the data are counted. Table 5 shows the results of students' sentiment analysis on each theme of the reformed teaching method. There are 420 positive comments on the ease of model application, with a mean sentiment score of 0.839; 425 positive comments on the accuracy of resource recommendations, with a mean sentiment score of 0.867; 411 positive comments on the quality of the resources, with a mean sentiment score of 0.845; and 432 positive comments on the diversity of resources, with a mean sentiment score of 0.870. The sentiment scores are all more than 0.830, with predominantly positive sentiment, which shows that students have a high level of satisfaction with the use of models to assist the teaching of the programmable controller technology course.

Table 5: The results of sentiment analysis on each topic

Theme	Number of comments on this topic	Number of comments with positive emotional tendencies	Number of comments with negative emotional tendencies	Number of comments with a neutral emotional tendency	Average emotional score
Convenience of model application (C)	448	420	28	0	0.839
Accuracy of resource recommendation (A)	461	425	36	0	0.867
Resource quality (RQ)	459	411	48	0	0.845
Resource diversity (RD)	462	432	30	0	0.870

IV. B. 2) Importance and satisfaction statistics

Figure 6 shows the importance and satisfaction levels for each evaluation theme. Importance and satisfaction are basically in a synchronized trend. The highest importance is the diversity of resources, which reaches 0.864, and it is also the theme with the highest satisfaction of students, with a satisfaction level of 0.870. The second most important is the accuracy of resource recommendation, which is 0.859, and the satisfaction level reaches 0.867.The second is the quality of resources and the ease of model application. It can be seen that students are most concerned about the effectiveness of the resources, i.e., whether they can be provided with effective resource recommendations.

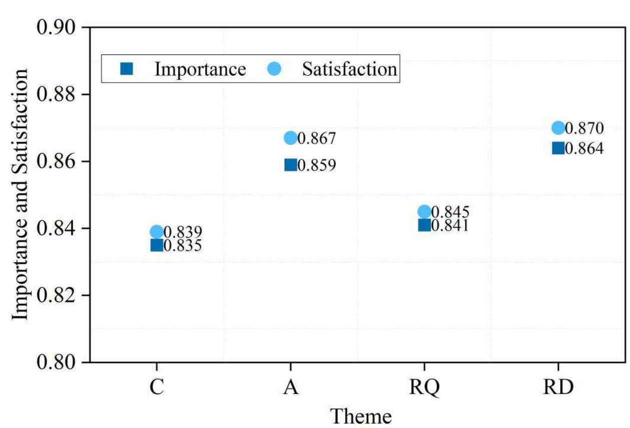

Figure 6: The importance and satisfaction distribution of each evaluation topic

V. Conclusion

This paper integrates process knowledge discovery and hierarchical recommendation mechanism to realize industrial case-driven programmable controller teaching reform. The HECR model has better resource recommendation effect than the comparison model in all 6 evaluation indexes in 2 datasets. When the resource level is 10, the loss function value of the model is finally stabilized at 0.0512, and the values of the 2 evaluation indexes are higher than 0.60, at which time the resource recommendation effect is the best. The average value of students' satisfaction with the reformed teaching method is more than 0.830, and they are more concerned about the actual recommendation effect of resources. In the future, we can explore the dynamic knowledge map update mechanism to realize the real-time update of resources, so that the teaching of programmable controller technology courses can keep pace with the times.

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