ISSN 2663-8169 Vol. 7, Issue 3: 61-67, DOI: 10.25236/IJNDE.2025.070310

Research and Practice of a Knowledge Graph-Driven Digital Multidimensional Reconstruction Strategy for Courses: A Case Study of the "Urban Railway Communication and Signal" Course

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Abstract: *Aiming at the problems of knowledge systematic weakness, insufficient dynamic adaptation of resources and single evaluation dimension in the digital transformation of vocational education courses, a multi-dimensional reconstruction framework for courses driven by knowledge graph is proposed. Based on the construction practice of "Urban Railway Communication and Signal", systematic innovation is carried out in the three dimensions of content architecture, teaching mode and evaluation system. Through the construction of domain knowledge semantic network architecture, the logical association of course knowledge modules, skill elements and human development connotation is realized, which significantly enhances the structural integration effectiveness of teaching resources; the "dynamic adaptive teaching strategy of virtual and real linkage" is designed to realize the dynamic generation of personalized learning sequences by using the path of knowledge graph, which effectively enhances the depth of interaction between teachers and students and their ability of practical migration; the composite evaluation model based on vocational ability mapping is developed to systematically construct the teaching mode covering the knowledge content and the evaluation system. Developing a composite evaluation model based on vocational competence mapping systematically builds a multi-dimensional monitoring system covering knowledge internalization, skill formation and value recognition. The research results show that the framework can strengthen the intelligent adaptation of teaching resources, the dynamic generation of teaching process and the three-dimensional diagnostic function of learning evaluation, forming a collaborative innovation paradigm of "knowledge structuring - learning personalization - evaluation value-added", which provides a practical reference of the in-depth integration of knowledge construction and value orientation for the digital transformation of vocational education, and effectively promotes the innovation of value and optimization of path of digital transformation of education. It effectively promotes the value innovation and path optimization of education digital transformation.*

Keywords: *Knowledge graph; course digitization; multidimensional reconfiguration; composite evaluation; gold course construction*

1. Introduction

Digital technology has had a profound impact on the traditional teaching mode of higher vocational courses, which can optimize the teaching structure, break the limitation of time and space, innovate the teaching method, change the learning mode, and promote the development of the evaluation system. As the infrastructure of cognitive intelligence, knowledge graph both undertakes the function of knowledge representation and supports the knowledge reasoning of generative artificial intelligence. It describes entities and their relationships in symbolic form through the semantic network and knowledge base of directed graph structure, displays information through ternary (entity-relationship-entity) [1], visualizes the hierarchy and logic of knowledge, captures the complex connections of knowledge, realizes in-depth semantic analysis and reasoning, and provides users with precise and personalized knowledge services [1,2]. The application of knowledge graph in the field of education provides new development space for teaching and learning, especially in the digital transformation of vocational education courses, which provides new ideas and technologies. It reveals the deep connection between course content and learning objectives through visual knowledge representation, improves the allocation of educational resources,

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and creates customized learning paths for learners. In higher education, course knowledge graph is the key to building a smart education system, which presents knowledge points and their connections through a networked structure to help learners master course content in depth.

Urban Railway Communication and Signal is a basic course for the higher vocational urban rail transit operation management profession, which has an important impact on students' professionalism and subsequent course learning. Currently, the teaching content of the course deviates from the job standards, and the solidification of the learning path leads to the obstacle of skill migration. The purpose of this paper is to construct the knowledge graph of the course "Urban Railway Communication and Signal" through the four links of enterprise research-knowledge element extraction-ontology modeling-dynamic updating, develop a four-step progressive model to reconstruct the teaching process, realize the digital reform of the course, and provide a new perspective for future research to promote the development of vocational education curriculum.

2. Current Status of Research

In the field of education, the OELD project in the UK promotes the sharing of educational resources through an open data platform [3], while Knewton in the US has established a large knowledge network to promote the recommendation of personalized learning resources [4]. Domestic scholars are also actively exploring the application of knowledge graph in education. Guo Z pointed out that digital reforms need to make more use of new technologies [5]. Yu S developed a knowledge graph for parenting aimed at helping students to overcome the difficulties in their growth [6]. Lang Y et al. constructed a knowledge graph for a C++ course, which provides inference and recommendation functions [7]. Zhang C et al. developed knowledge graph and inference for a math curriculum technology [8]. Huang J constructed a Python knowledge graph for secondary school students to improve learning efficiency [9]. Zhou J reconstructed the knowledge system of the Civics course and formed a knowledge graph [10]. Wang X conducted a systematic analysis of the e-commerce course and proposed a structured organization method of the course resources [11]. Tang Y et al. constructed a library of course Civics materials [12]. Shi J et al. proposed a knowledge graph for emerging areas of curriculum resources based on the knowledge graph of emerging field course resource construction method [13]. Cheng P and Fan X help to improve the teaching effect by constructing the knowledge graph of the course "Cloud Accounting and Intelligent Financial Sharing" [14]. Zeng L and Li Q believe that knowledge graph supports interdisciplinary education and cultivates new talents [15]. Pang L shows how to use digital means to improve the practical training effect of the course Passenger Management in Rail Transportation Stations [16]. Existing studies show that there are three research gaps in knowledge graph of vocational education courses: insufficient job matching refinement [4,14], limited adaptability of teaching dynamics [8,15], and lack of evaluation data integration mechanism [6,10], which constitute the breakthrough direction of this study.

3. Framework Design

This study follows the path of "problem identification, in-depth analysis, effective solution, implementation and feedback, application and promotion". First, through industry research, expert interviews, questionnaires and other means, we identify the problems in the digital construction of courses, such as fragmentation of resources, disconnection with job requirements, and imperfect evaluation system. Then, these problems are analyzed in depth, key influencing factors are identified, and solutions are explored. Next, based on the analysis results, solutions are designed to clarify the course objectives, construct knowledge maps and job maps, reconstruct teaching resources, develop new resources, and design digital teaching programs and diversified evaluation systems. During the implementation process, digital resources are applied to teaching, feedback is collected, adjustments and optimization are made, and a closed-loop improvement mechanism is formed. Problems and opinions in the implementation are collected through questionnaires, interviews, teaching logs, etc., and the root causes of the problems are analyzed and fed back to the analysis stage to provide a basis for optimization. Finally, summarize and promote the research results that have been tested and corrected in practice, continuously optimize the program, form a replicable and scalable model, and promote the overall digital transformation of education and teaching.

3.1. Determine the Goal and Scope of the Construction of the Knowledge Graph

The "five-step" strategy is adopted to define the objectives and scope of the construction of

ISSN 2663-8169 Vol. 7, Issue 3: 61-67, DOI: 10.25236/IJNDE.2025.070310

knowledge graph. This strategy involves identifying the area of specialization of the course, defining the knowledge boundaries, specifying the purpose of the construction, the scope of data sources, and the target users, to ensure that the construction process has a clear direction and limitations. The course content starts with the history of communication and signal systems to establish basic concepts, and then goes into detail about the equipment of signal systems, such as signaling machines, track circuits, rutting machines, and axle counters, as well as the transmission, support, and operational subsystems of communication systems, including clocks, power supplies, and centralized alarms. The construction of the course knowledge map follows this logical structure.

3.2. Knowledge Element Extraction

In the data preparation stage, this study combed the collected resources such as teaching courseware, teaching videos, exercises, cases, and literature to extract the knowledge points related to the application of urban rail transit communication and signaling equipment, and classified and organized them. The BERT-BiLSTM-CRF hybrid model [17] was used to carry out the knowledge extraction of unstructured text and integrated into the course knowledge. The core concepts of the course were systematically listed, filtered, summarized and organized, and the structured, well-defined and resourceful concepts were classified and their levels and attributes were defined.

3.3. Knowledge Graph Construction and Visualization

Design the knowledge graph structure, including elements such as nodes, edges, attributes, and their interrelationships. Nodes represent entities and edges represent relationships between entities. Based on the previous research, use big data and AI platform technology to intelligently process teaching resources, including data preprocessing, entity recognition, relationship extraction, graph database construction and visualization. The preprocessing steps include word splitting, deactivation, and lexical labeling. Natural Language Processing (NLP) tools are used to recognize entities in the text, such as names of people and places, and to identify relationships between entities, which are represented by directed connecting lines between knowledge points, including prior knowledge, posterior knowledge and associated knowledge. The entities and relationships are stored in a graph database, such as Neo4j, and the Gephi algorithm is applied for force-directed layout to achieve optimal presentation of the topology [18]. The initially constructed curriculum knowledge graph includes 15 items and about 93 core knowledge points.

Through the construction of AI curriculum resources, a new type of curriculum resources based on the knowledge graph was developed and the graph was constructed on the Chaoxing platform. For example, when learning “individual operation of turnouts”, the knowledge map not only displays the relevant content, but also reveals the knowledge points of “interlocking equipment” that are closely related to turnouts, as well as the case studies and resources related to them. The knowledge graph not only displays the content, but also reveals knowledge points about interlocking devices that are closely related to turnouts, as well as associated case studies and resources. When searching for “interlocking equipment”, knowledge points related to “signaling machine”, “track section”, “rutting machine”, etc. are displayed, as well as knowledge points between them. When searching “interlocking equipment”, the knowledge points related to “signaling machine”, “track section”, “rutting machine” and so on will be displayed, as well as the main relationship network formed between the knowledge points.

3.4. Digitalization Strategy

(1) Digitization of teaching design

Based on the digitalization of the industry and the job requirements of urban rail transportation, reconstruct the course content of Urban Railway Communication and Signal. Define the types of knowledge and cognitive dimensions, and construct an accurate course knowledge system. Take the knowledge points as the core, use data analysis to understand the learning situation, design subjective learning activities, and promote the development of students' thinking ability. For example, by arranging the main learning activity of analyzing the cause of the Shanghai Metro “9-27” accident, discussing how to prevent similar accidents through communication and signaling technology. Utilizing the platform of “Super Star Learning Channel” to provide inquiry activities before and after class to cultivate students' multidimensional ability. For example, a field trip is arranged before the class to let students visualize the operating environment of urban rail transit communication and signal systems. The course content centers on the development history of signaling and communication systems, trackside signaling equipment, interlocking equipment, train control equipment, communication equipment, and other basic

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knowledge, working principles and applications, focusing on basic knowledge and core principles.

(2) Digitization of teaching resources

Summarize and mine course knowledge points through knowledge graph, providing multi-dimensional resources such as pictures, mind maps, texts, and videos. Teachers can release practice questions and case studies in real time so that students can apply their knowledge in practice. Constructing knowledge graph, sorting out knowledge points, optimizing delivery methods, enriching resources, establishing digital resource libraries, and strengthening the elements of Civics. According to job requirements and industry standards, absorb new technologies, build a digital curriculum design framework, and develop teaching resources.

(3) Digitalization of teaching mode

Combining offline practical exercises and digital teaching, adopting a blended teaching mode, considering skills training and personalized development. For example, the application of the flipped classroom, students first online learning micro-teaching, classroom discussion and exploration.

(4) Digitalization of teaching methods

Explore the project-based teaching mode according to the characteristics of the course and the situation of students. Using knowledge graph for project-based teaching, selecting typical tasks, guiding students to sort out knowledge, improving learning efficiency, and playing the role of collaborative learning. For example, for the task of “understanding relays”, teachers can help students deeply understand the basic principles and use of relays through the explanation of the working principle of relays and other key knowledge points, and then combined with specific tasks, guide students to use what they have learned to carry out the preparation of interlocking tables.

(5) Digitalization of teaching evaluation

Adopt value-added evaluation and utilize knowledge graph to promote the reform of each teaching link. Enhance classroom efficiency and quality through digital means, reform assessment methods, consider students' unique learning paths, and form personal learning growth portraits. Let students become the main body of evaluation and emphasize the development of vocational ability.

(6) Digitalization of effect feedback

Apply digital resources to collect learning, teaching feedback, and implementation effects. Collect problems and opinions through questionnaires and interviews, analyze the root causes of problems and optimize teaching. Customize personalized learning paths, provide multimodal resources to meet different learning needs, and dynamically adjust learning paths to improve learning effects.

4. Practice Path

4.1. Implementation Process

Knowledge graph provides a platform for teachers to communicate and cooperate, which promotes the sharing of teaching experience and the improvement of teaching level. Based on the constructed knowledge map, teachers prepare lessons independently according to school characteristics and teaching needs, and flexibly choose the content of lectures with a wide range of application. Through the reorganization of module contents, curriculum resources are revitalized and their application value is enhanced. The digital curriculum is disseminated through computer and Internet technology, which makes the learning content richer and more flexible, and the learning modes freer and more diversified, meets the demand for personalized learning, cultivates the ability of innovation and cooperation, and promotes educational equity and resource sharing.

In the teaching process, the digital curriculum based on knowledge graph follows the principles of human-centeredness, diversity and openness, encourages students' active participation and interaction, and improves learning effectiveness. Combining online and offline evaluation, process and result evaluation, it realizes an accurate, comprehensive and diversified evaluation mode and promotes the improvement of teaching quality. Curriculum knowledge graph can be embedded into mainstream teaching platforms, such as Chaoxing platform, and applied to the construction of learner profiles, teachers' learning situation analysis and evaluation diagnosis, as well as students' personalized curriculum resource recommendation. In terms of constructing learner profiles, the characteristics and behavioral samples of learners are used to refine the traits and construct profiles, which provide data

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support and validation materials for professional talent cultivation programs. In terms of learning situation analysis and evaluation and diagnosis, the use of knowledge graph assists teachers in conducting accurate learning situation analysis and evaluation, visualizing learner information, objectively analyzing data, finding learning weaknesses, and promoting learning progress. In terms of course resource recommendation, learning resource recommendation based on knowledge graph can mine relationships from massive resources, provide learners with effective recommendations, save time, improve search efficiency, and attract learners' interest through visualization.

4.2. Typical Application Scenarios

In the practice scenario of urban rail interlocking system debugging teaching program, traditional teaching faces core contradictions such as high complexity of equipment cognition and large cost of safety trial and error. Based on the knowledge map-driven curriculum dynamic reconstruction framework, this study builds a three-layer closed-loop teaching model of "cognitive modeling-virtual-real interaction-behavioral correction". First, relying on the knowledge graph ontology model (Content Reconstruction), semantically labeling the interlocking table interpretation, wiring logic verification, and other core skills of the pilot knowledge dependency relationship, through the dynamic learning path generation technology, to break through the bottleneck of "knowledge faults caused by the operation of the disorder" in the skills learning. Secondly, at the level of teaching implementation (Teaching Reconstruction), combined with the AR equipment information scanning trigger mechanism, the physical equipment is disassembled into interactive three-dimensional dynamic schematic diagrams, and through the drag-and-drop parameter modification, fault simulation and other virtual and real linkage tasks, the teaching of the "structural cognitive blindness visualization, abstract operational processes Finally, docking evaluation reconstruction dimension (Evaluation Reconstruction), designing virtual work order system to collect real-time operation track data, constructing error type attribution model based on occupational ability mapping, and implementing instant behavioral interception and case retrospective warning for high-frequency risk points such as miswiring and logical checking omission, simultaneously generating learners' competence warning, and simultaneously generating learners' competence and knowledge. It also generates a learner's ability deviation portrait to drive personalized compensation learning. This scenario effectively verifies the dual closed-loop mechanism of "knowledge transfer - ability internalization - value penetration" driven by knowledge graph and provides a fusion solution of cognitive construction and behavioral training for high-risk and high-complexity vocational education practice.

5. Practice effect

The digital course reform of "Urban Railway Communication and Signal" based on knowledge graph has achieved remarkable results, and its application value is mainly reflected in three dimensions.

5.1. Knowledge Construction Efficacy Enhancement

By constructing a semantic network containing 15 equipment modules and 93 core knowledge points, knowledge graph effectively solves the problem of knowledge fragmentation existing in the traditional teaching mode. Teaching observations show that learners can quickly locate the precursor knowledge nodes of complex modules such as urban rail transit interlocking system with the help of topology visualization mapping, and show a more systematic cognitive framework in the virtual-realistic AR equipment disassembly practical training. Teachers' feedback indicates that the intelligent retrieval system of teaching resources based on the Neo4j graph database significantly improves the efficiency of explaining difficult knowledge such as the principle of urban rail rutting machine.

5.2. Dynamic Optimization of Learning Path

Knowledge mapping significantly broadens the learning path of students. Compared with the traditional knowledge system diagram, knowledge graph helps students discover connections, eliminate blind spots, and summarize and precipitate knowledge by visualizing the relationship between concepts and knowledge points. The search module and discussion forum further enhance the learning effect. The search function improves the efficiency of information retrieval, and the discussion forum increases interactivity and stimulates new thinking. Knowledge graph provides students with a new way of learning, effectively promoting learning and knowledge mastery. The real-time operational feedback that learners

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get through the virtual work order system effectively reduces the risk of misuse of key skills such as interlock table preparation. Especially in the practical aspects of axle counter troubleshooting, the case library associated with the knowledge map builds a progressive problem-solving ladder for learners, forming a closed loop of "knowledge retrieval→program deduction→operational validation" ability cultivation. The knowledge map assists teachers in curriculum construction and teaching reform. It integrates the knowledge points of communication and signal system to form a complete knowledge system, which helps teachers reasonably organize the teaching content, design the course structure and teaching progress, and improve the teaching quality.

5.3. Teaching Management Paradigm Innovation

Knowledge graph realizes comprehensive and personalized teaching management. In terms of teaching content, it systematizes and integrates the knowledge points so that students can master the course content comprehensively. In terms of teaching methods, we design lively and interesting activities, such as case studies, to stimulate students' motivation. In terms of learning situation, comprehensive tracking and analysis, timely detection and resolution of student difficulties. In terms of teaching resources, the online teaching platform is intelligent and provides abundant resources. The personalized education system provides corresponding knowledge point mapping according to students' learning stages, recommends knowledge points of interest, and improves learning efficiency and satisfaction.

6. Conclusion

The application of knowledge graph technology in the field of education has shown a mature degree of technical implementation, capable of constructing subject knowledge systems and recommending personalized learning paths. This study closely combines the urban rail transit communication and signaling course with the ability requirements of intelligent operation management positions to ensure the practicality and relevance of the reform. The study establishes the theoretical support for the digital reform of the course, provides a clear guiding ideology and implementation path, and aims to improve the efficiency of the organization of the teaching content and the logic of teaching; the proposed digital teaching implementation and evaluation system improves the learning monitoring, evaluation, and feedback through visualization, and improves the quality of teaching and student experience. It is expected to promote the reform results in vocational colleges and universities in Zhejiang Province, which has a demonstration effect and promotes wider educational reform; the proposed teaching strategy based on knowledge graph has become an effective way to improve teaching quality. The application of knowledge graph not only enhances students' understanding of communication and signal system knowledge, but also strengthens their learning interest and motivation, and at the same time helps teachers to grasp the whole picture of the course, adjust the teaching progress in time, and ensure students' comprehensive and in-depth learning.

Knowledge graph shows significant advantages in the field of multidisciplinary intersection, especially in dealing with complex and convergent problems. Knowledge graph technology provides a diverse reform model for vocational education, although it still faces technical and scenario challenges in educational applications. This study conducts a preliminary exploration of the construction of curriculum knowledge graph, and plans to incorporate more educational content and further improve the resources in the future.

At the theoretical level, this study proposes a "knowledge-scenario-competency" paradigm for digitizing vocational education courses, and verifies the leverage of knowledge graph in shortening the time lag between education supply and industrial demand. At the practical level, for schools, it is suggested that the school-enterprise co-construction working group can help establish a regularized maintenance mechanism for the curriculum knowledge map; for teachers, it is recommended to change the dominant thinking of "textbook logic" and build the reverse design capability of "job task→knowledge unit"; for teachers, it is recommended to change the dominant thinking of "textbook logic" and build the reverse design capability of "job task→knowledge unit". However, this paper has some limitations. However, there are some limitations in this paper, for example, it does not cover the coordinated reconstruction of cross-specialty course groups for the time being, and the in-depth mining of learning behavior data needs to be strengthened. In the future, the teaching team will further develop knowledge fusion technology, build a knowledge engine with knowledge map as the core of the course, and integrate it with the work tasks and cutting-edge research in the urban rail industry, to improve the quality of course teaching.

ISSN 2663-8169 Vol. 7, Issue 3: 61-67, DOI: 10.25236/IJNDE.2025.070310

Acknowledgments

Fund Projects

1) The Second Batch of Teaching Reform Project of "14th Five-Year Plan" for Higher Vocational Education in Zhejiang Province: Research and Practice of "1112" Mode of Value-added Evaluation of Vocational Ability of Urban Railway Operation and Management Majors Based on COMET. The project number is jg20240056.

2) The School-level Teaching Reform Research and Practice Project of Zhejiang Institute of Communications in 2024: Research and Application of Digital Reform of Courses Based on "Knowledge Graph"-Taking "Urban Railway Communication and Signal" Course as an Example. The project number is 2024JG38.

3) University-Industry Cooperation Collaborative Education Program of Zhejiang in 2023: Exploration and Practice of the Five-in-One Collaborative Education Mode of "Post, Class, Training, Race and Research" in the Context of Intelligent Logistics. The project number is Zhejiang Education Office Letter [2023] 241 (313).

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