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Research on the Establishment and Teaching Application of Knowledge Graphs for Building Physical Models

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Abstract: Under the background of the deep integration of engineering education accreditation and intelligent teaching, practical teaching in civil engineering majors is confronted with practical predicaments such as fragmented knowledge, weak correlation among courses, and insufficient transformation of physical resources into teaching. To solve this difficult problem, this article attempts to rely on the Intelligent Construction Comprehensive Training Hall of Harbin Petroleum Institute, deeply integrate knowledge graph technology with the teaching of architectural entity models, adopt a top-down mode, construct a five-level correlation system of "professional training objectives - ability requirements - curriculum system - knowledge point system - model nodes", and build a micro-lesson video resource library as a supporting measure. A complete teaching reform path of "graph construction - resource matching - teaching application - feedback optimization" has been formed, striving to strengthen the knowledge linkage among courses, enhance students' autonomous learning ability and higher-order thinking quality, and provide a replicable and scalable teaching solution for the cultivation of high-quality applied talents in civil engineering majors.

Keywords: building physical model, knowledge graph, outcome-based education teaching philosophy, visualized teaching

1. Introduction

With the transformation of China's construction industry towards intelligence and green development, the industry has put forward higher requirements for the engineering practice ability, systematic thinking ability and innovation ability of civil engineering professionals. The standards for engineering education accreditation clearly state that professional teaching should focus on "the combination of theory and practice" and "the systematicness and integrity of the knowledge system". As the core carrier connecting theoretical knowledge and engineering practice, architectural entity models play an irreplaceable role in practical teaching (Zhang & Liang, 2023). Harbin Institute of Petroleum completed the construction of the Intelligent Construction Comprehensive Training Hall in 2021. The architectural physical models in the hall cover two major systems: structural force and node construction, and contain 155 learning modules and 276 teaching nodes, providing students with an intuitive engineering cognition platform.

However, in the long-term teaching practice, traditional entity model teaching has exposed significant limitations: First, knowledge transmission is fragmented. Teachers often focus on the corresponding nodes of a single course when teaching and ignore the knowledge connections across courses, making it difficult for students to construct a complete professional knowledge system. Secondly, the logical correlation of courses is weak. When multiple courses share the same model node, due to the lack of systematic integration, it is easy to cause repetitive perception of teaching content and fail to effectively cultivate students' higher-order thinking. Thirdly, the transformation of resources is insufficient. The teaching value of physical models is restricted by time and space, making it difficult to meet the usage needs of intern students and self-motivated learners after class.

Meanwhile, as an important application achievement of artificial intelligence technology in the field of education, knowledge graphs, with their triplet structure of "entity - relationship - attribute",

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can structure and visualize scattered knowledge elements, providing a brand-new technical path for solving the problem of knowledge fragmentation (Lu, 2025). At present, knowledge graphs have significant advantages in the reconstruction of curriculum systems and personalized learning guidance, but their targeted application in the teaching of physical models for civil engineering majors is still in the exploratory stage. Based on this, this article focuses on the pain points of teaching in civil engineering majors, introduces knowledge graph technology into the teaching of building entity models, and conducts systematic teaching reform practices, providing new impetus for the improvement of teaching quality.

2. Establishment of a Knowledge Graph for Building Physical Models

2.1 Establish mode selection

There are mainly two modes for knowledge graph construction: top-down and bottom-up. The bottom-up model starts from specific data and gradually forms a top-level knowledge system through knowledge extraction and integration. It is suitable for scenarios with abundant data but ambiguous structure. The top-down model starts from the top-level knowledge framework and gradually decomposes it to specific entities, making it suitable for fields with mature knowledge systems and clear structures (Guan & Cai, 2024).

Considering that the curriculum system of civil engineering majors is complete, the training objectives are clear, and the reverse design logic of the OBE concept must be strictly followed, this paper ultimately chooses the top-down construction mode. This model can ensure a high degree of alignment between the knowledge graph and the professional training objectives and ability requirements, avoid confusion in the knowledge system, and at the same time improve the construction efficiency and guarantee the systematicness and practicality of the graph.

2.2 Five-level system framework design

Based on the OBE concept, this study constructs a five-level correlation system of “professional training objectives - ability requirements - curriculum system - knowledge point system - model nodes”, and the connotations and correlation logics of each level are as follows:

The first-level “Professional Training Objectives”: Focusing on the talent cultivation orientation of majors such as civil engineering, engineering management, engineering cost, and building environment and energy application engineering, it clearly defines the professional qualities, professional knowledge, and engineering capabilities that students should possess after graduation, such as “having the ability to manage the entire process of engineering cost” and “mastering the basic principles of civil engineering structural design”, etc.

The second-level “Competency Requirements”: The training objectives are decomposed into core competency modules such as engineering design, construction organization and management, cost control, and problem-solving. Each module is further refined into specific indicators. For instance, “engineering design competency” can be broken down into “construction drawing reading competency” and “structural component design competency”, etc.

The third level, “Curriculum System”: Select course clusters that support the cultivation of core competencies, which are divided into core courses and elective courses. Core courses include “Engineering Measurement and Valuation”, “Engineering Cost Management”, etc., to ensure a precise match between curriculum design and competency requirements.

The fourth level “Knowledge Point System”: Break down the teaching content of each course, distinguish between core knowledge points and extended knowledge points, and clarify their connotations, difficulty levels and interrelationships. For example, the core knowledge points of “Engineering Measurement and Valuation” include “Rules for Calculating Engineering Quantities” and “Methods for Engineering Valuation”, etc.

Level 5 “Model Nodes”: Correspond the knowledge points one-to-one with the architectural entity model nodes of the Intelligent Construction Comprehensive Training Hall, clearly defining the teaching functions and application scenarios of each model node. For instance, the knowledge point of “Flexural bearing Capacity of the normal Section of reinforced concrete beams” corresponds to the “Reinforcement Arrangement in the Tensile Zone” node of the “reinforced concrete beam model”.

2.3 Specific construction steps

2.3.1 Data collection and standardization processing

Data collection covers three types of core materials: The first is teaching document type, including professional training programs, teaching syllabuses, etc., which are used to sort out training objectives, ability requirements and curriculum systems; The second category is physical resource type, which collects structural drawings, technical parameters, QR code associated resources, etc. of the building physical model, and clarifies the basic information of the model nodes. The third category is teaching feedback. Through methods such as questionnaires, interviews with teachers and students, and homework analysis, high-frequency questions and error-prone points in students' model learning and knowledge point understanding are collected to provide a basis for the optimization of the graph and the construction of the resource library. And standardize the collected data: convert unstructured data such as teaching syllabus texts and interview records into structured data, and unify the data format and naming norms; Clear duplicate and incorrect data to ensure accuracy and consistency; Establish a standardized dataset to lay the foundation for subsequent knowledge extraction (Wang, 2024).

2.3.2 Knowledge extraction and association establishment

Adopt a hybrid approach of "manual extraction + tool assistance" to complete knowledge extraction and association establishment: The first is the definition of the ontology and model, based on the five-level system framework, clearly defining five types of core entities (including training objectives, abilities, courses, knowledge points, and model nodes), four types of core relationships (including "support", "inclusion", "correspondence", and "association"), and attribute types (course credits, knowledge point difficulty, node numbers, etc.). The second is specific knowledge extraction, extracting entity, relationship and attribute information from standardized datasets: For instance, the "Training Objectives of the Engineering Cost Major" supports "cost control ability", and "cost control ability" is supported by the "Engineering Measurement and Valuation" course. "Engineering Measurement and Valuation" includes the knowledge point of "Rules for Calculating Engineering Quantities", and this knowledge point corresponds to the "Dimension marking" node of "Concrete Structure Component Model". At the same time, collect entity attribute information, such as the course "Engineering Measurement and Valuation" with 3.0 credits, 48 class hours, and the target students of the 2023 grade cost major, etc.

2.3.3 Knowledge integration and redundancy elimination

During the knowledge integration stage, two core tasks are mainly accomplished: First, entity alignment. Entities with different names but the same connotation are uniformly named. For instance, "Engineering Valuation" and "Engineering Pricing" are unified as "Engineering Measurement and Pricing" to avoid entity redundancy. The second is relationship integration, which involves sorting out the indirect connections among entities and supplementing the missing relationship links. For instance, it can establish the connections between different courses through the corresponding relationship of "knowledge points - model nodes", thereby strengthening the linkage effect of course clusters. At the same time, clean up the duplicate relationships and conflicting attributes during the extraction process: delete completely duplicate triplet data; For attribute conflicts such as inconsistent class hours for the same course, verify and correct them by reviewing the original teaching documents and consulting the instructors to ensure the accuracy of the knowledge graph.

2.3.4 Visual presentation and platform deployment

The Neo4j graph database tool is utilized to achieve the visual presentation of knowledge graphs. This tool supports the graphical display of entities and relationships, and features multi-dimensional queries, graph scaling, node highlighting, and other functions (Liu, 2024). The visualization graph adopts a hierarchical display design: the top layer showcases the professional training objectives and core competencies, the middle layer presents the curriculum system and knowledge points, and the bottom layer displays the model nodes. Teachers and students can click on the entities to view detailed attribute information and related resources (such as course Outlines, knowledge point explanation videos, model drawings, etc.). Deploy the knowledge graph to the HIP intelligent platform and simultaneously connect it to the Rain Classroom online teaching platform to achieve dual-end access on both PC and mobile terminals. The graph is equipped with multi-dimensional search functions, supporting search by entity name, attribute information, and relationship type, thereby enhancing the efficiency of knowledge acquisition.

2.4 Construction of the micro-lesson video resource library

Based on the teaching feedback data collected in the early stage, focusing on the high-frequency questions and error-prone knowledge points of students, and combining the teaching focus of architectural entity models, three types of micro-lesson videos are constructed: The first type is the knowledge point explanation type, which provides concrete explanations for the abstract and difficult core knowledge points in combination with the model structure; The second category is model operation demonstration type, which showcases the structure and composition of the model, disassembly and assembly processes, and identification of key parts, etc. The third category is engineering case analysis, which explains the application of model knowledge points in engineering practice in combination with actual engineering projects.

Each micro-lesson video should be controlled within 5 to 8 minutes in duration, adopting a structure of “principle explanation - model demonstration - summary and refinement” : the opening should concisely introduce the core connotation of the knowledge point. The middle part combines physical model shooting or animation demonstration to visually present the relevant principles and application scenarios. Summarize the key points at the end to strengthen students’ memory. The video is equipped with clear subtitles and knowledge point annotations, making it convenient for students to quickly locate key information.

3. Teaching Application Design and Practice of Building Entity Model Knowledge Graph

3.1 Teaching application concepts and strategies

Adhering to the teaching application concept of “student-centered, ability-oriented, and technology-supported”: Through the visualization and systematization characteristics of knowledge graphs, help students build a complete professional knowledge system. By leveraging the micro-lesson resource library and the Rain Classroom platform, the personalized learning needs of students are met. With the cultivation of abilities as the core, the application of knowledge graphs is closely integrated with the development of engineering practice ability and systems thinking ability, achieving a coordinated development of “knowledge imparting - ability cultivation - quality improvement”. Please refer to Figure 1 for details.

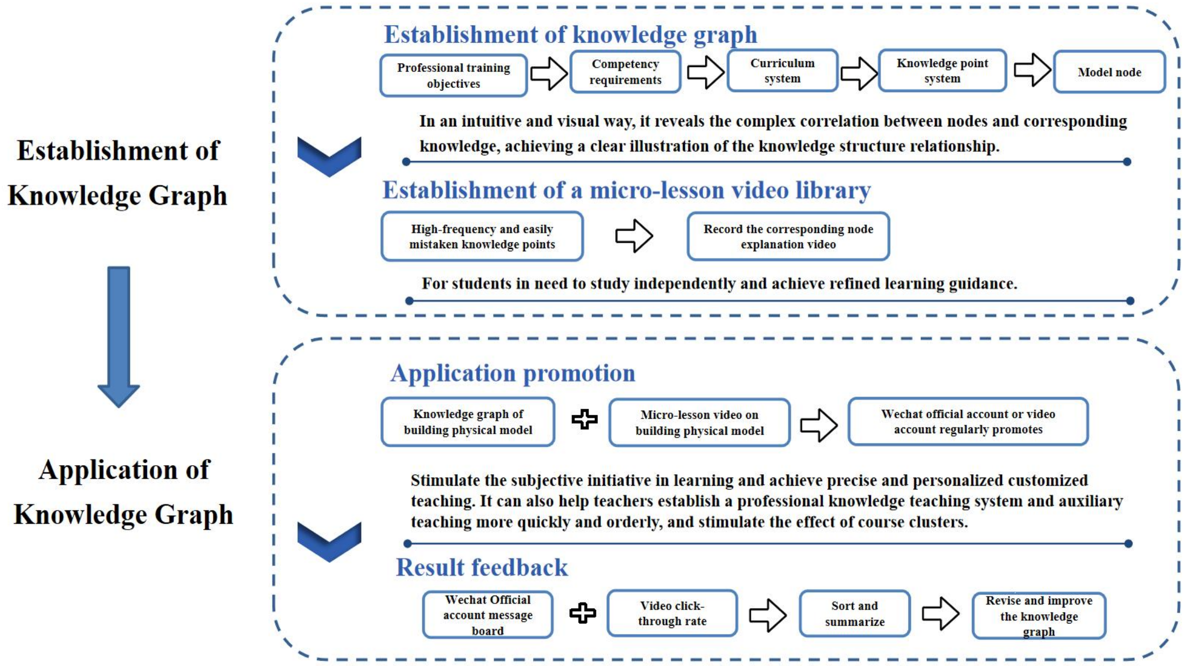

Figure 1 Shows the Overall Design of the Teaching of the Knowledge Graph for Building Entity Models

Teaching application forms a closed-loop process: Through the establishment of knowledge graphs and the construction of micro-lesson video libraries, core elements such as professional training objectives, curriculum systems, and model nodes are integrated; Relying on platforms such as WeChat official accounts and video accounts, promote the knowledge graph of architectural entity models and micro-lesson videos to stimulate students’ subjective initiative in learning, achieve precise and personalized teaching, and at the same time assist teachers in building teaching systems and stimulating the effect of course clusters. Collect feedback through channels such as the platform’s message board and video click-through rates, organize and summarize it, and then optimize and improve the knowledge graph.

3.2 Multi-scenario teaching application model

3.2.1 Application in classroom teaching scenarios

In classroom teaching, knowledge graphs and micro-lesson resource libraries are mainly used to assist in teaching and interaction. In the course introduction stage, teachers use graphs to display the positioning of the knowledge points of this class in the professional knowledge system, their connection with previous and subsequent courses, and the corresponding architectural entity models, helping students establish an overall cognition. During the key and difficult points explanation section, relevant micro-lesson videos are played simultaneously with the demonstration of physical models. Through the approach of “physical objects + videos + explanations”, the abstract is transformed into the concrete to help students understand. During the classroom interaction session, students access the knowledge graph through mobile terminals to search for relevant information, conduct group discussions on the points of doubt, and teachers quickly answer questions with the help of the graph to enhance the efficiency of interaction (Yang, 2025).

3.2.2 Application of autonomous learning scenarios

Knowledge graphs and micro-lesson resource libraries provide full-process support for students’ autonomous learning: During the pre-class preview stage, students understand the framework of course knowledge points and their correlations with the knowledge they have learned through knowledge graphs, watch relevant micro-lesson videos and model introductions, and master the basic content in advance. During the supplementary stage of the class, you can consult the diagrams and videos at any time according to the progress of the teacher’s explanation to deepen your understanding. During the post-class review stage, the knowledge framework is sorted out through graphs. For weak knowledge points, videos are repeatedly watched. Combined with practical exercises of physical models, the mastery of knowledge is strengthened (Wang K., 2020).

For groups such as intern students who cannot have on-site contact with physical models, they can access the knowledge graph and resource library through mobile terminals, remotely learn the relevant knowledge points and operation demonstrations of the model, solve the practical problems encountered during the internship, and achieve an autonomous learning mode of “learning anytime and anywhere”.

3.2.3 Teaching evaluation and feedback scenarios

The application of knowledge graphs and the Rain Classroom platform provides diversified data support for teaching evaluation: Teachers can analyze students’ graph access records, video viewing duration, and frequency of knowledge point queries, etc., to grasp students’ learning interests and weak points, and adjust teaching strategies. Based on the completion of homework and test scores, an evaluation system that combines process assessment with summative assessment is formed.

At the same time, establish a multi-channel feedback mechanism: First, the Rain Classroom online message board, where students can provide feedback on usage issues and improvement suggestions at any time; Second, regular questionnaire surveys are conducted. Two surveys on the satisfaction of teachers and students are carried out each semester to understand the application effects and demands of teaching. The third is feedback from teaching and research activities. Through collective lesson preparation and teaching seminars, teachers’ teaching experiences and problems are collected. Classify and organize the feedback information to form a problem list, providing a basis for the optimization of the knowledge graph and the update of the resource library (Guo, 2024).

4. Conclusion

This article aims at the problems existing in the teaching of physical models in civil engineering majors, such as fragmented knowledge, weak course correlation, and insufficient resource transformation. Based on the OBE concept, it constructs a five-level correlation knowledge graph of architectural physical models, namely “professional training objectives - ability requirements - curriculum system - knowledge point system - model nodes”, and builds a micro-lesson video resource library as a supporting facility. A complete closed loop of teaching reform has been formed.

Practice has proved that the top-down construction mode is compatible with the mature knowledge system of civil engineering majors and can ensure that the knowledge graph is highly consistent with the talent cultivation goals. The visualization graph supported by the Neo4j tool enables the intuitive presentation of knowledge associations, breaking down the knowledge barriers between courses. The multi-scenario teaching application model not only assists teachers in building a systematic teaching system and enhancing the efficiency of classroom interaction, but also provides students with personalized and full-process autonomous learning support, effectively solving the time and space limitations of traditional teaching. In addition, the "feedback-optimization" mechanism ensures the dynamic improvement of the knowledge graph and resource library, enabling them to continuously adapt to changes in teaching needs.

Overall, through the deep integration of knowledge graph technology and architectural entity model teaching, this article provides a replicable and scalable practical solution for the teaching reform of civil engineering majors. It not only enhances the teaching quality and students' engineering practice ability and systematic thinking ability, but also offers strong support for the cultivation of high-quality applied engineering and technical talents. In the future, the application scope can be further expanded, exploring the integration path of knowledge graphs with technologies such as artificial intelligence and virtual reality, continuously deepening the reform of smart teaching, and providing more high-quality talents for the development of the industry.

Conflict of Interest

The authors declare that they have no conflicts of interest to this work.

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