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Research on the Reform Path of "Fundamentals of Circuit Analysis" Empowered by Knowledge Graphs

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Abstract: Under the background of the development of emerging engineering disciplines and the digital transformation of education, the curriculum reform of "Fundamentals of Circuit Analysis" has become an urgent priority. Focusing on the application of knowledge graphs in this curriculum reform, this paper conducts an in-depth analysis of its enabling pathways. By sorting out the curriculum's knowledge system, integrating interdisciplinary knowledge, and constructing multi-dimensional knowledge graphs, the structured and interconnected presentation of knowledge is achieved. Leveraging knowledge graphs to optimize the organization of teaching resources, implement blended teaching, promote personalized learning, and improve the intelligent evaluation system, the transformation of the teaching model from "knowledge point indoctrination" to "competence-oriented" is realized. This provides a theoretical basis and practical plan for cultivating compound engineering talents with interdisciplinary thinking and practical abilities.

Keywords: New engineering; Knowledge graph; "Fundamentals of Circuit Analysis"; Blended learning

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1. Introduction

With the comprehensive advancement of emerging engineering disciplines, construction and the in-depth implementation of the educational digitalization strategy, university curriculum teaching is facing unprecedented challenges and opportunities. As a core foundational course for majors such as Electrical Engineering, Electronic Engineering, and Automation, "Fundamentals of Circuit Analysis" plays a pivotal role in shaping students' engineering thinking, developing learning methods, and fostering a craftsman's spirit [1]. However, under the traditional teaching model, the teaching of "Fundamentals of Circuit Analysis" is often carried out chapter by chapter, making it easy for students to engage in fragmented learning and difficult to form a systematic understanding of the course knowledge. The course content has problems such as scattered knowledge points and weak correlations, which make it difficult to meet the needs of emerging engineering disciplines for cultivating compound talents. As an emerging technology, knowledge graphs can effectively integrate knowledge and reveal the inherent connections between knowledge. The organic integration of knowledge graph technology and the content of "Fundamentals of Circuit Analysis" helps construct a structured and visualized knowledge system, expand interdisciplinary research fields, and provide innovative ideas and methods for curriculum reform [2]. Using knowledge graphs to sort out the course knowledge system, select appropriate intelligent teaching resources for development based on the characteristics of the course and students' needs, and build a rich digital resource library including microlecture videos, interactive courseware, and virtual experiment modules. Integrating digital resources into knowledge graphs can create a network with abundant resources to meet students' diverse learning needs.

2. Reconstruction of the course knowledge system based on knowledge graphs

Focusing on the "Fundamentals of Circuit Analysis" course, a visual knowledge graph is constructed, and a multi-dimensional knowledge graph is developed by combining the knowledge connection points of prerequisite and subsequent courses. Knowledge points and their relationships are digitally represented to form a curriculum knowledge network with a topological structure. This graph not only presents the overall framework of the knowledge system but also reveals the attribute characteristics and association paths of each knowledge point, laying a foundation for the subsequent organization of intelligent teaching resources and the planning of personalized learning paths. Through this reconstruction of the knowledge system, the transformation from traditional linear knowledge transmission to networked and structured knowledge construction is realized, effectively supporting the achievement of the talent training goals of emerging engineering disciplines. The construction method of the knowledge graph for "Fundamentals of Circuit Analysis" is shown in **Figure 1**.

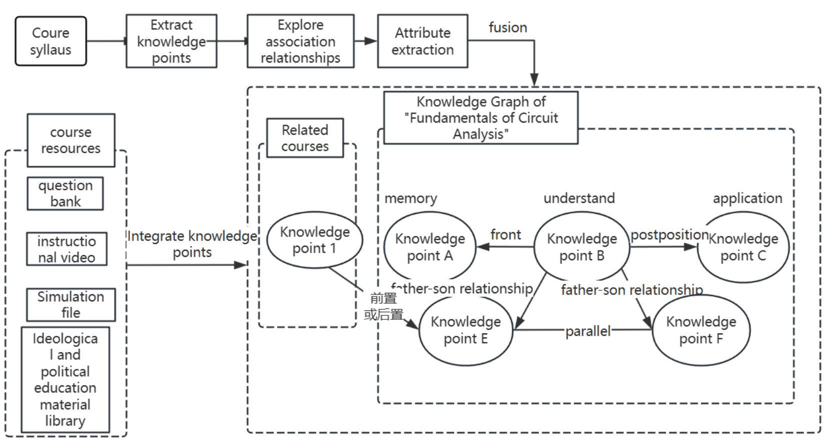

Figure 1. Knowledge graph construction method.

2.1. Construction of the course knowledge graph

Combining the engineering education certification standards and the needs of industrial digital transformation, the focus is on strengthening students' engineering practice capabilities and digital literacy. The teaching objectives of the traditional "Fundamentals of Circuit Analysis" course are upgraded to clearly cultivate students' abilities in circuit modeling, simulation analysis, and solving complex engineering problems. Starting from the course objectives, decomposed teaching objectives in three aspects (knowledge, ability, and value) are established, teaching content and resources are sorted out, the granularity of knowledge points is refined, and course objectives, teaching objectives, knowledge points, and engineering practice analysis are connected with the knowledge graph [3]. Based on the revised curriculum syllabus, a structured analysis method is used to deconstruct the content of “Fundamentals of Circuit Analysis,” sorting out core knowledge modules such as “Basic Circuit Laws,” “Dynamic Circuit Analysis,” and “Frequency Domain Analysis Methods,” which are then refined into individual knowledge point units. Finally, a knowledge representation model is designed to clarify the attributes of knowledge points (such as difficulty coefficient, importance level, prerequisite knowledge, etc.) and association relationships (such as sequential relationships, inclusion relationships, application relationships, etc.). For example, Kirchhoff’s Laws were previously taught as a whole in a 90-minute class period; through the construction of the knowledge graph, the knowledge points are sorted out and decomposed into two knowledge points: Kirchhoff’s Current Law (KCL) and Kirchhoff’s Voltage Law (KVL). The VCR relationships of circuit components and the directions of voltage and current are set as prerequisite knowledge points for these two laws, and Kirchhoff’s Laws in sinusoidal AC circuits are set as subsequent knowledge points, constructing a complete knowledge network of Kirchhoff’s Laws in the course.

2.2. Horizontal integration graph

Based on the content of “Fundamentals of Circuit Analysis,” the focus is on constructing a knowledge association network between mathematics (calculus, linear algebra), physics (basic electromagnetism), and circuit theory to address the cognitive barriers of freshmen in interdisciplinary connections and promote the integration of knowledge. When students encounter difficulties in circuit analysis (such as solving differential equations of dynamic circuits), the system can automatically associate and recommend corresponding review content of mathematical foundations (such as the solution method of first-order differential equations), helping students fill knowledge gaps and improve learning efficiency.

2.3. Vertical progression graph

The construction of the vertical progression graph focuses on building a complete knowledge development context, forming a progressive learning path of “basic theory → analysis method → engineering application”. For the “Fundamentals of Circuit Analysis” course, taking “time-domain analysis → frequency-domain analysis → system synthesis” as the main line, the core teaching content is systematically integrated to construct a hierarchical knowledge progression system. It breaks the limitation of isolated presentation of knowledge points in traditional teaching, forming a logically rigorous and hierarchically clear knowledge development path, effectively supporting students’ ability leap from basic theory to engineering application, which is in line with the progressive requirements of emerging engineering talents training.

2.4. In-depth expansion graph

The construction of the in-depth expansion graph aims to break the course boundaries and establish a knowledge bridge between “Fundamentals of Circuit Analysis” and subsequent professional courses. By systematically sorting out the extended applications of circuit theory in engineering practice, a knowledge expansion network oriented to practical engineering problems is constructed, focusing on strengthening students’ knowledge transfer ability and engineering thinking cultivation. It not only enhances students’ knowledge transfer ability of “basic theory - professional courses - engineering practice” but also cultivates their systematic engineering thinking, effectively solving the problems of course separation and knowledge fragmentation in traditional teaching, and providing a coherent knowledge development path for the ability training of emerging engineering talents. Through explicit knowledge association annotation, it helps students establish a complete professional knowledge system and improve their comprehensive ability to solve complex engineering problems.

2.5. Integration of teaching resources

The construction of knowledge graphs not only realizes the structuring of knowledge but also provides a core framework for the systematic integration and intelligent application of teaching resources. The course team takes the knowledge graph as the "hub" to accurately anchor and semantically associate originally discrete and heterogeneous teaching resources (including textbooks, academic literature, microlecture videos, interactive courseware, virtual simulation experiments, question banks, engineering cases, etc.) with the knowledge point nodes in the graph. For example, when students focus on the knowledge point of "Kirchhoff's Laws", the knowledge graph can not only present its conceptual definition but also actively push associated prerequisite review resources (such as "VCR of Circuit Components" videos), core explanation resources (such as interactive courseware for law derivation), application verification resources (such as virtual experiments for circuit simulation), and consolidation and expansion resources (such as hierarchical exercise sets and practical engineering application cases). In this way, the knowledge graph acts as an "intelligent knowledge navigation", providing students with a highly contextualized and integrated learning environment. It greatly improves the efficiency of students in locating and using resources, effectively supporting on-demand learning and personalized exploration, meeting the diverse learning needs of students at different levels, and laying a solid resource foundation for the blended teaching and personalized learning paths described in the subsequent chapters.

3. Application of knowledge graphs in teaching model innovation

Based on the structured and associated course knowledge system constructed by knowledge graphs, the teaching model of "Fundamentals of Circuit Analysis" has been systematically innovated. Knowledge graphs not only serve as content organization tools but also become the core engine driving the reconstruction of teaching processes and the transformation of learning methods, which are specifically reflected in the following aspects.

3.1. Construction of a blended teaching model based on knowledge graphs

Relying on knowledge graphs, a deeply integrated "online-offline" blended teaching model is constructed [4]. Before class, teachers accurately design learning task chains based on the knowledge point network and association relationships in the knowledge graph, and push personalized preview resource packages (such as micro-videos, prerequisite knowledge review materials, etc.) to students through online platforms. During class, teachers use knowledge graphs to visually present core knowledge points and their multi-dimensional associations, guide students to carry out inquiry-based and discussion-based learning, focus on explaining key nodes and complex associations in the knowledge network, and help students construct a systematic knowledge structure. After class, the system automatically assembles homework and extended learning resources according to the knowledge graph to strengthen students' mastery of weak links in the knowledge network. This model effectively solves the problems of fragmented knowledge presentation and implicit logical associations in traditional teaching, realizing the transformation from "teacher-centered" to "student-centered" and from "knowledge indoctrination" to "thinking training."

3.2. Planning of personalized learning paths based on knowledge graphs

Knowledge graphs provide a technical foundation for the real realization of personalized learning. By recording students' learning behaviors (such as video viewing duration, exercise accuracy rate, virtual experiment operation trajectory, etc.), the system dynamically evaluates their mastery of each knowledge node, and intelligently plans and dynamically adjusts learning paths based on the topological relationships (such as prerequisite dependencies, difficulty progression) and semantic associations of the knowledge graph [5]. For example, when the system detects that a student has difficulties in the knowledge point of "time-domain analysis of first-order dynamic circuits," it can automatically trace back and recommend the learning of prerequisite knowledge points such as "solution of differential equations" or "VCR relationships of capacitor and inductor components," or horizontally associate with the "mathematical foundation review module" to achieve precise knowledge supplement and ability enhancement; for students with spare capacity, based on the "in-depth expansion graph," it recommends extended application resources of "Fundamentals of Circuit Analysis" in subsequent professional courses such as "power system analysis" and "electronic circuit design" (such as simple amplifier circuit design cases based on circuit analysis), guiding them to carry out inquiry-based learning. This closed-loop mechanism of "evaluation - recommendation - learning - re-evaluation" ensures that students carry out efficient learning within their "zone of proximal development," effectively respecting individual differences among students.

3.3. Empowering process-oriented intelligent evaluation and feedback

Breaking through the traditional single evaluation model of "final assessment + regular homework", taking knowledge graphs as the data carrier, a multi-dimensional intelligent evaluation system of "process-oriented evaluation + summative evaluation + ability dimension evaluation" is constructed to realize a comprehensive and dynamic evaluation of students' learning effects and ability development. The system accurately anchors various assessment tasks, such as homework, quizzes, and projects, to the knowledge points in the knowledge graph, enabling formative evaluation of students' learning outcomes with finer granularity and wider dimensions. It can not only evaluate students' mastery of individual knowledge points but also assess their ability to integrate and apply knowledge by analyzing their performance in complex problems involving multiple associated knowledge points. The analysis based on the graph can generate visual learning situation reports, providing teachers with an overall perspective of the class's knowledge mastery situation to help them adjust teaching strategies; at the same time, it provides students with personalized learning diagnosis and feedback, clarifying the strengths and weaknesses in their knowledge network, and guiding them to carry out independent targeted enhancement.

3.4. Driving the deep integration of virtual simulation and inquiry-based learning

Combining the virtual experiment modules and simulation resources associated with knowledge graphs, the course vigorously promotes inquiry-based learning of "learning by doing". Knowledge graphs structurally associate theoretical knowledge points with corresponding virtual experiments and engineering case simulations. After learning a certain theory (such as "resonant circuits"), students can immediately enter the virtual experiment platform through the graph entrance to independently build circuits, modify parameters, observe phenomena, verify theories, and explore engineering application scenarios associated with knowledge nodes (such as "frequency-selective circuits of radio receivers"). This seamless switching between "theory and practice" based on knowledge graphs materializes abstract theories, greatly enhancing students' learning immersion and initiative, and effectively cultivating their engineering practice capabilities and innovative thinking.

4. Conclusion

Through the path and practice of knowledge graph-empowered curriculum reform of "Fundamentals of Circuit Analysis," multi-dimensional course knowledge graphs (horizontal integration, vertical progression, in-depth expansion) are constructed, realizing the structured, associated, and systematic reconstruction of the course knowledge system, and effectively solving the problems of knowledge fragmentation and weak correlations in traditional teaching. On this basis, knowledge graphs have driven a series of teaching innovations such as blended teaching models, personalized learning path planning, intelligent evaluation systems, and virtual inquiry-based learning, successfully promoting the fundamental transformation of course teaching from "teacher-centered knowledge indoctrination" to "student ability development-centered". It provides an effective solution for cultivating compound emerging engineering talents with solid theoretical foundations, interdisciplinary thinking, and engineering practice capabilities.

Future research can be further advanced from three aspects:

(1) Construct a dynamically updated knowledge graph ecosystem, establish a tripartite collaborative graph update mechanism of "universities - enterprises - certification institutions" in combination with the needs of industrial digital transformation and the iteration rhythm of course content, and real-time incorporate new circuit technologies, engineering practice cases, and certification standard requirements to ensure the timeliness and practicality of the knowledge system;

(2) Optimize the intelligent adaptation model of personalized learning paths, introduce cognitive science theories, construct multi-dimensional learner portraits integrating "knowledge foundation - cognitive style - learning scenarios", and use machine learning algorithms to realize the dynamic adjustment and precise push of learning paths, improving the personalization level of learning support;

(3) Improve the multi-scenario evaluation mechanism of the intelligent evaluation system, build a virtual-real integrated engineering practice platform, track students' operation processes and problem-solving ideas in real circuit experiments and engineering projects through Internet of Things technology, and combine the associated data of knowledge graphs to construct a dual-dimensional ability evaluation model of "process + result", further improving the scientificity and application value of evaluation results, and providing more precise quality assurance for the training of emerging engineering talents.

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