Research on Curriculum Content Reconstruction and Teaching Practice of Communication Electronic Circuits Based on Knowledge Graph

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Abstract: *The knowledge system of the Communication Electronic Circuit course has the basic characteristics of dense concepts and complex logical associations. The traditional linear chapter structure fails to present the multidimensional associations among knowledge points, and the content update lags behind under the background of technological iteration. Knowledge graph technology provides a new technical path for course organization: it constructs the hierarchical framework of subject knowledge through ontology modeling, mines the semantic associations among knowledge points, integrates multi-source heterogeneous teaching resources, and forms a computable and navigable course knowledge graph. Then it performs modular reorganization and topological optimization of the knowledge system, designs cross-chapter integration paths, and plans navigation sequences oriented toward cognitive logic. The teaching form driven by the knowledge graph enables the dynamic generation of course content, the visual interaction of knowledge, and the graph-based regulation of learners' cognitive load. The course reconstruction based on the knowledge graph can improve the systematicness of knowledge organization, enhance the adaptability of the course to disciplinary development, and provide structured support for differentiated teaching.*

Keywords: *knowledge graph; Communication Electronic Circuit; course content reconstruction; knowledge modeling; semantic association; cognitive navigation*

Introduction

The Communication Electronic Circuit course covers a complete knowledge system from device characteristics to system architecture, and it serves as the hub connecting basic circuits and the communication major. This course includes core functional modules such as amplifiers and mixers, and complex logical dependency relationships exist among the knowledge units. The current course mostly adopts a linear chapter structure, which cuts the complete knowledge network into relatively independent units, and learners find it difficult to form an overall cognition of the disciplinary system. Meanwhile, technological evolution in the field of communication electronics is rapid, and a time lag exists between the course content and the development of engineering technology; therefore, the course reform needs to balance knowledge systematicness and dynamic adaptability. As a semantic network knowledge representation method, the knowledge graph can formally describe subject concepts and their associations. Constructing a course knowledge graph to reorganize the knowledge organization method and exploring the graph-driven evolution of teaching forms have research value for improving the course teaching effectiveness and adapting to disciplinary development.

1. Construction Mechanism of the Knowledge Graph for the Communication Electronic Circuit Course

1.1 Modeling and Hierarchical Architecture of the Subject Knowledge Ontology

The knowledge system of the Communication Electronic Circuit course covers multi-level content ranging from low frequency to high frequency and from unit circuits to system integration. Its complexity determines that knowledge organization needs to be built upon a rigorous ontological modeling foundation. The construction of the subject knowledge ontology begins with the extraction and definition of the core concepts of the course, including basic component characteristics, amplifier configuration principles, oscillation and feedback principles, and modulation and demodulation techniques. Through the formal description of the connotation and extension of these concepts, the class relationships and attribute characteristics of these concepts are clarified, and a computable set of knowledge units is formed.

On the basis of concept definition, a hierarchical architecture of the knowledge system is further constructed. According to the internal logic of the Communication Electronic Circuit course, the knowledge points are divided into three progressive dimensions: the basic theory layer, the functional circuit layer, and the system application layer. The basic theory layer covers the fundamentals of semiconductor physics and signal analysis tools, the functional circuit layer focuses on various amplification, oscillation, mixing, and filtering circuit topologies, and the system application layer involves the architectural design of receivers and transmitters. Through this hierarchical division, the evolution path of knowledge from abstract principles to concrete implementation is clearly presented, and a structural foundation is laid for subsequent knowledge association mining and resource organization[1].

1.2 Mining and Representation of Semantic Associations Among Knowledge Units

Complex logical dependency relationships exist among the knowledge points in the Communication Electronic Circuit course, and a simple list of concepts cannot reflect the integrity of the disciplinary knowledge. The mining of semantic associations requires a systematic analysis of causal, supportive, similarity-based, and derivational relationships among the knowledge points. For example, the design of an oscillator circuit depends on the mastery of feedback control theory, and the performance analysis of a mixer requires the integration of basic concepts of nonlinear circuits. By sorting out these internal connections, a multidimensional relationship network among the knowledge points is established, so that the knowledge graph not only stores facts but also contains the disciplinary logic.

On the basis of relationship mining, these associations are formally represented using semantic network technology. Different types of association edges are defined: for example, the "prerequisite-successor" relationship is used to indicate the learning sequence, the "parameter-function" relationship is used to connect circuit specifications and implementation methods, and the "principle-application" relationship is used to bridge theoretical knowledge and engineering practice. By assigning clear semantic types and weight attributes to the association edges, the knowledge graph can support complex reasoning and navigation functions. This representation method transforms static knowledge points into a dynamic knowledge network, and it provides the underlying support for the reorganization and optimization of the course content.

1.3 Fusion and Representation Methods for Multi-Source Heterogeneous Knowledge Resources

The teaching resources of the Communication Electronic Circuit course exhibit significant multi-source heterogeneous characteristics, which include theoretical descriptions in textbook texts, topological structures in circuit atlases, waveform data in simulation software, and measured results in experimental platforms. To incorporate these resources of different forms into a unified knowledge graph, it is necessary to address the alignment of resource granularity and the indexing of features. For textual resources, natural language processing technology is used to extract key concepts and relationship descriptions. For graphical resources, image recognition is applied to parse circuit connections and component parameters. For simulation data, quantitative features such as frequency response and gain curves are extracted to form indexable resource nodes.

The key to the fusion of heterogeneous resources lies in establishing a mapping mechanism between the resources and the knowledge units. Each teaching resource is annotated with its corresponding core concepts and associated relationships, thereby forming multiple links between resource nodes and concept nodes. For example, a simulation file about an amplitude modulation circuit is linked not only to the concept of "amplitude modulation principle" but also to related units such as "multiplier circuit" and "envelope detection." Through this many-to-many mapping method, the knowledge graph becomes a bridge connecting abstract theories and concrete examples, and learners can freely switch between conceptual understanding and engineering application, thus improving their overall grasp of the disciplinary knowledge.

2. Reconstruction Path of the Course Knowledge System Based on the Knowledge Graph

2.1 Modular Reorganization and Topological Optimization of the Knowledge System

The traditional Communication Electronic Circuit course mostly follows a linear arrangement of chapter-by-chapter progression, gradually moving from semiconductor devices and basic amplifier circuits to high-frequency oscillation and modulation techniques. Although this arrangement conforms to the stage characteristics of knowledge accumulation, it, to some extent, fragments the intrinsic connections among the knowledge points. The introduction of the knowledge graph provides the possibility to break this linear structure. Based on the concept association degrees and functional clustering characteristics revealed in the graph, the course content can be re-divided into several knowledge modules with internal logical cohesion. For example, nonlinear circuits, mixers, and frequency multipliers related to frequency transformation are aggregated into a "frequency transformation technology" module, and resonant circuits, filters, and frequency-selective amplifiers related to signal selection are integrated into a "frequency-selective network and filtering" module. This modular reorganization takes the intrinsic logical associations of knowledge as the link, and it makes the course structure closer to the systematicness of the discipline itself[2].

On the basis of modularization, the knowledge topological structure is further optimized. With the help of the strength and types of semantic associations in the graph, the core nodes and key paths in the knowledge network are identified. For the hub knowledge points located at the intersection of multiple paths, such as the principle of negative feedback and the concept of impedance matching, a prerequisite and bridging status is given to them in the course arrangement, making them the bridges connecting different modules. For knowledge points with sparse associations or strong independence, they are treated as supplementary content within the modules for local deepening. Through this topological optimization, the knowledge system of the course evolves from a linear sequence into a hierarchical and networked organic structure, which not only retains the progressive logic of knowledge transmission but also strengthens the conceptual echo across chapters, thus building a more systematic disciplinary cognitive framework for learners.

2.2 Fusion and Integration Design of Cross-Chapter Knowledge Nodes

In the Communication Electronic Circuit course, there exist a large number of knowledge nodes that cross the boundaries of traditional chapters, and these nodes are often the key to understanding complex circuit systems. Taking the oscillator design as an example, it involves multiple knowledge elements distributed across different chapters, such as the principle of transistor amplification, feedback control theory, frequency-selective network characteristics, and frequency stability analysis. In the traditional course arrangement, these elements are taught separately, and learners find it difficult to form an overall cognition of oscillator design. The fusion design based on the knowledge graph aims to reconnect these dispersed knowledge nodes, thus forming aggregated knowledge units centered on core issues.

The realization of the fusion design depends on the explicit expression of cross-hierarchical associations in the graph. By marking the multi-hop paths between the "oscillator" node and nodes such as "amplifier circuit", "feedback criterion", and "resonant circuit" in the graph, the position and reachability relationships of the oscillator in the knowledge network are clarified. In terms of course content organization, these associated nodes can be reorganized according to their logical dependency relationships, and topical knowledge clusters centered on functional circuits such as oscillators, amplifiers, and mixers can be designed. By tracing the association paths in the graph, learners can understand, within the same cognitive framework, how knowledge from different chapters cooperates to realize specific circuit functions. This integrated design integrates the dispersed knowledge points into function-oriented knowledge chains, strengthens the mapping relationship between theory and engineering practice, and shifts the course content from a list of knowledge points to the presentation of a knowledge network.

2.3 Planning of Knowledge Navigation Paths Oriented Toward Cognitive Logic

The learner's cognitive process follows the progressive law from concrete to abstract and from simple to complex. Although the multidimensional association network presented by the knowledge graph fully reflects the knowledge structure of the discipline, facing the complex network directly may increase the cognitive load. Therefore, it is necessary to plan knowledge navigation paths oriented toward cognitive logic on the basis of the graph, so as to provide learners with clear learning sequence guidance. The planning of navigation paths is based on the dependency relationships in the knowledge graph, and it identifies the prerequisite requirements and subsequent extensions of each knowledge node. For knowledge points with obvious dependency relationships, such as the "amplitude modulation principle" needs to be learned after the "multiplier circuit", and the "phase-locked loop" needs to be developed after the "feedback control", the path planning ensures that the learning sequence conforms to the internal logic of knowledge.

The planning of navigation paths also needs to consider the differences in learning objectives and individual needs. For different learning stages and task requirements, multiple selectable path sequences are extracted from the graph. The basic path focuses on the coverage of core concepts and the cultivation of key skills, and it proceeds sequentially along the backbone nodes in the graph. The extended path delves into the edge nodes of the graph, introducing more specialized circuit topologies or cutting-edge technologies. The paths are connected to each other through shared nodes in the graph, and learners can flexibly switch between the backbone and branches according to their own understanding progress. This multi-path navigation design based on the graph not only ensures the systematicness and coherence of knowledge transmission but also provides structured support for differentiated learning, thus making the organization of course content better adapt to the learners' cognitive laws[3].

3. The Evolution of Course Teaching Forms Driven by the Knowledge Graph

3.1 The Dynamic Generation Mode of Course Content Supported by the Knowledge Graph

The field of Communication Electronic Circuit undergoes rapid technological iteration, and new circuit topologies, integrated devices, and modulation methods continue to emerge, which places high demands on the timeliness of course content. The update cycle of traditional textbooks is relatively long, and they fail to reflect the cutting-edge progress of the discipline in a timely manner, resulting in a time lag between course content and the development of engineering technology. The introduction of the knowledge graph provides technical support for the dynamic generation of course content. The graph itself has scalability, and new knowledge nodes can be incrementally incorporated by defining their attributes and their association relationships with existing nodes. When a new technology, such as software-defined radio architecture or a new type of power amplifier topology, reaches a consensus in the discipline, it can be embedded into the corresponding position of the knowledge network through graph editing tools, and its logical associations with basic concepts and functional circuits are clarified. This process not only completes the addition of new knowledge but also triggers the automatic update of the association paths, ensuring the logical consistency between the new nodes and the existing knowledge system, thus keeping the course content always synchronized with the development of the discipline.

The dynamic generation mode based on the knowledge graph further changes the organization mode of the course content. The knowledge associations stored in the graph can serve as the basis for content screening and combination, so the generation of course content shifts from static arrangement to on-demand aggregation. At different stages of course instruction, corresponding subgraphs can be extracted from the graph according to the teaching theme, thus forming micro-course units focused on specific topics. For example, when teaching modern receiver architecture, the associated subgraph of nodes such as the mixer, local oscillator, filter, and analog-to-digital converter can be extracted from the graph and linked to the corresponding theoretical explanations and simulation cases. This graph-based content generation mode enables the course system to have adaptability to the development of the discipline, and it can organically integrate new content into the existing framework while maintaining knowledge systematicness. The subgraphs corresponding to different teaching themes can be automatically generated based on the association strengths and logical hierarchies in the graph, thus avoiding the rigidity and lag of the course content and forming a dynamic course content evolution mechanism that collaborates with the evolution of the discipline[4].

3.2 Design of Knowledge Visualization Presentation and Multidimensional Interaction Mechanism

The Communication Electronic Circuit course involves a large number of abstract concepts and complex signal flows, and its knowledge representation has strong spatial and dynamic characteristics. Traditional text and static diagrams have certain limitations in transmitting such knowledge, and learners find it difficult to build a dynamic imagination of the signal transformation process and circuit behavior in static media. The visualization technology of the knowledge graph provides a new approach for improving knowledge representation. By presenting the knowledge network of the course in the form of a node-link diagram, learners can intuitively perceive the relative positions and association densities of each knowledge unit, thus forming a spatial cognition of the overall structure of the discipline. For concepts involving parameter changes, such as oscillation conditions and frequency response, the dynamic adjustment of visualization elements can present the trend of circuit behavior changing with component parameters, thereby giving concrete expression to abstract processes such as frequency drift and gain change, and transforming implicit signal relationships into explicit visual features.

The design of the multidimensional interaction mechanism further enhances the depth of interaction between learners and the knowledge network. In the visualization interface of the graph, learners can click on a node to expand the knowledge details associated with it, trace the derivation paths or engineering mapping relationships between concepts, and thus achieve nonlinear exploration of the knowledge network. For composite structures such as multistage amplifier circuits or phase-locked loops, the layer switching function allows learners to traverse between the overall block diagram and the details of unit circuits, enabling them to establish cognitive connections between different levels of abstraction. The trajectory data generated during the interaction process can also be used to analyze learners' exploration preferences in the knowledge network, identify their hot spots of interest and nodes that are prone to confusion, and provide data support for subsequent navigation optimization and content arrangement. This design, which integrates visualization and interaction, transforms the knowledge graph from a storage structure into a cognitive tool, allowing learners to gradually construct an overall understanding of the disciplinary system of Communication Electronic Circuit through active exploration, thus realizing a transformation in cognitive style from passive reception to active construction[5].

3.3 Graph-Based Regulation Strategy for Learners' Cognitive Load

Although the complex network structure presented by the knowledge graph fully reflects the internal associations of the discipline, presenting it directly without filtering may exceed the learners' information processing capacity and cause a high cognitive load. The regulation of the graph presentation mode becomes the key link for optimizing the learning experience. Based on the controllable information density characteristic of the graph, the display granularity of the graph can be dynamically adjusted according to the learners' knowledge reserve and learning stage. When learners first encounter a new concept, only the core nodes and backbone associations are presented, and detailed attributes and edge links are hidden, so that learners can focus on the establishment of the basic framework and avoid cognitive disorientation caused by information overload. After the core concepts are mastered, the secondary nodes and cross-layer associations are gradually expanded, guiding learners to deeply understand the complexity of knowledge. This approach keeps the density growth of the knowledge network synchronized with the development of the learners' cognitive abilities, thus forming a gradual cognitive advancement path.

The graph-based regulation strategy can also be used for the personalized guidance of learning paths. By tracking the learners' navigation trajectories and dwell times on the graph, the system can infer their mastery levels and cognitive preferences for different knowledge nodes. For nodes with short dwell times or frequent skips, the system appropriately highlights them through visual weight adjustment in the graph, indicating that these key connection points in the knowledge network require attention. For nodes that have been repeatedly visited, the system reduces their prominence and guides the learners to expand toward related areas, thus avoiding cognitive stagnation on a single node. In complex circuit analysis tasks, the graph can automatically mark the subset of knowledge points relevant to the current task, compress irrelevant information, and reduce the external cognitive load during the task process, so that learners can focus their cognitive resources on solving the core problem. This graph-based regulation mechanism transforms the control of cognitive load from passive outcome evaluation to active process guidance, provides a structured implementation path for differentiated teaching, and enables learners with different starting points to obtain a learning experience matching their cognitive states under the support of the graph.

Conclusion

This study focuses on the knowledge organization problem of the Communication Electronic Circuit course, and it explores the reconstruction path of the course content based on the knowledge graph. At the level of the construction mechanism, the hierarchical modeling of the subject knowledge ontology achieves a clear definition of the class relationships and hierarchical structure of the knowledge units; the mining and representation of semantic associations establish a multidimensional relationship network among the knowledge points; and the fusion mapping of multi-source heterogeneous resources realizes the connection between abstract concepts and engineering examples. At the level of the reconstruction path, modular reorganization and topological optimization are carried out based on the knowledge associations revealed by the graph, which promotes the transformation of the course structure from a linear sequence to a networked system; the fusion design of cross-chapter knowledge nodes forms function-oriented knowledge aggregation units; and the planning of multi-path navigation sequences according to cognitive laws provides structured support for differentiated learning. At the level of the teaching form, the graph supports the dynamic generation of course content and enhances the adaptability of the course to disciplinary development; the knowledge visualization and multidimensional interaction mechanism transform the graph into a cognitive tool; and the graph-based regulation strategy for cognitive load achieves a dynamic match between information density and learners’ cognitive abilities. This study provides a systematic knowledge organization framework for the Communication Electronic Circuit course. Subsequent research can focus on the automatic construction and update mechanism of the graph, graph-based learning behavior analysis, and the transfer application of graph technology to other professional courses.

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References

[1] Hu, H., et al. "Exploration of Teaching Practice in 'Communication Principles' Driven by Knowledge Graph and Large Language Models." Physics and Engineering, pp. 1-9.
[2] Zhu, M., and Sun, K. "Discussion on Innovative Methods of Teaching Reform for the 'Communication Electronic Circuit' Course." Journal of Electrical and Electronic Education, Vol. 47, No. 05 (2025), pp. 132-134.
[3] Zhang, X. "Integrated Teaching Design and Practice in the Communication Electronic Circuit Course." Application of Integrated Circuits, Vol. 41, No. 06 (2024), pp. 202-203.
[4] Wang, S., and Zheng, R. "Practical Exploration of Teaching Reform for the Communication Electronic Circuit Course in Colleges and Universities." Computer Knowledge and Technology, Vol. 19, No. 19 (2023), pp. 165-166, 177.
[5] Shi, X., Chen, J., and Jin, W. "Design and Implementation of Project-Based Practical Teaching for the Communication Electronic Circuit Course." Laboratory Science, Vol. 25, No. 03 (2022), pp. 133-136.