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Visual Design and Teaching Application of the Knowledge Framework in the Computer Network Course

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Abstract: Aiming at the problems of complex content and abstract concept of the Computer Network course, and difficulty for students to establish overall cognition, this paper proposes a teaching framework that integrates knowledge graph and visualization technology. Firstly, through ontology modeling and multi-source data extraction, a course knowledge graph covering 180 core concepts and multi-level semantic relationships was constructed. Secondly, hierarchical, interactive, and thermal views were developed to dynamically present the knowledge structure, protocol process, and learning data. Finally, the visual graph was embedded into the flipped classroom and experimental links to realize personalized learning path recommendations and real-time mastery feedback. Teaching practice shows that the framework significantly improves students' overall cognitive level and learning motivation, and provides a reproducible and generalizable method framework and practical evidence for the smart teaching of computer courses.

Keywords: Knowledge graph; Visual teaching; Flipped classroom; Teaching effect

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1. Introduction

1.1. Research background and significance

In the era of information teaching, fragmented learning has become the norm, and it is generally difficult for students to form system cognition in the course of Computer Network because of cross-layer protocol stack, abstract concepts, and fast technology iteration. Transforming scattered knowledge points into intuitive and interactive semantic networks with the help of knowledge graphs and visualization methods not only conforms to the national strategy of "smart education," but also provides accurate teaching and research basis for teachers and personalized learning paths for students, so as to improve classroom efficiency and high-order ability cultivation, which has important theoretical value and broad practical prospects. In addition, with the construction of "new engineering" and the promotion of engineering education certification, the curriculum goal is no longer limited to the teaching of knowledge, but more emphasis is put on the cultivation of the ability to solve complex engineering problems. Traditional linear textbooks and PPT can no longer meet the needs of in-depth exploration. The semantic association and traceability characteristics of knowledge graphs provide a computable data basis for the evaluation of ability index achievement, which has demonstrative significance for promoting the teaching paradigm transformation of computer public courses and professional courses in colleges and universities [1,2].

1.2. Research status at home and abroad

In China, Tsinghua University, Zhejiang University, and other universities take the lead in introducing knowledge graphs into computer courses, mainly focusing on automatic extraction and association with a question bank. However, the systematic visualization research for "computer network" courses is still scarce, and the existing results mostly remain in the prototype display stage, lacking closed-loop practice and quantitative evaluation deeply integrated with flipped classroom and experimental teaching. In recent years, with the establishment of the "artificial intelligence + education" special fund, some teams have begun to try to build a course knowledge base based on Neo4j and provide concept search functions on the MOOC platform. However, the number of nodes is generally less than 2,000, the relationship type is single, and continuous support for the whole process of teaching has not yet formed. At the same time, it is still weak in cross-course knowledge transfer and dynamic recommendation of learning paths, and it is urgent to carry out fine design and long-term tracking combined with teaching scenarios [3,4].

In foreign countries, ACM and IEEE education communities have long advocated concept mapping and mind mapping. In the past five years, graph database and linked data technology have been used to build an adaptive learning system, which has achieved remarkable results in protocol interactive visualization and learning path recommendation. For example, the Massachusetts Institute of Technology's "Computer Networks" open course dynamically presents the TCP congestion control process through D3.js, and the University of Munich in Germany uses virtualized network experiments and knowledge graph linkage to realize real-time troubleshooting path tips. However, the course context and teaching objectives are quite different from those in China, and the details of the protocol are insufficient to map with Chinese terms, so it is difficult to adapt to the local teaching needs by direct transplantation. In addition, foreign studies pay more attention to the accuracy of personalized recommendation algorithms, and there is relatively little discussion on classroom collaboration, teacher's leading role, and big data ethics, which also provides a space for differentiated innovation for research in the Chinese context [5].

1.3. Research contents and methods

This study takes the construction of the knowledge graph of the "Computer Network" course as the core, comprehensively uses the content analysis method to comb out knowledge points, ontology modeling method to define semantic relationships, graph database technology to realize storage and update, and combines with the front-end visualization framework to develop hierarchical and interactive views. Through the embedding of flipped classroom and experimental teaching, questionnaire surveys, interviews, and learning analysis were used to evaluate the teaching effect, forming a complete research closed loop of "construction-application-evaluation-optimization." Specifically, firstly, according to the engineering education certification standards, the course objectives and graduation requirements indicators are deconstructed, and the top-down and bottom-up strategies are used to complete knowledge extraction and fusion. Secondly, an extensible data service layer is built based on Neo4j+GraphQL, and multi-terminal visualization components are developed by using D3.js, ECharts, and React. Then, two rounds of action research were used to iteratively improve the instructional design scheme. Finally, quantitative statistics and qualitative coding were used to confirm each other to comprehensively investigate the influence of knowledge graphs on students' academic performance, cognitive structure, learning motivation, and teachers' teaching behavior, and social network analysis and clustering algorithm were used to mine collaborative learning characteristics. This paper provides method references and practical experience for the subsequent interconnection of cross-course knowledge graphs and the ecological construction of intelligent education [6].

2. "Computer network" course analysis

2.1. Course characteristics and teaching objectives

"Computer Network" is a core basic course for computer majors, with the typical characteristics of "cross-layer protocol, model abstraction, rapid technology update, strong dependence on practice." On the one hand, the layered model of protocol stack divides the complex network communication process into physical layer, data link layer, network layer, transportation layer, and application layer. Each layer is independent and interdependent, and students need to establish an overall perspective of "vertical penetration and horizontal comparison." On the other hand, the course content expands rapidly with the emergence of new protocols such as IPv6, SDN, QUIC, and Internet of Things, which is difficult to be covered in time by traditional teaching materials. Under the background of engineering education certification, the teaching objectives of the course are subdivided into three dimensions: knowledge, ability, and literacy. At the knowledge level, students are required to master the five-layer (or TCP/IP four-layer) architecture, core protocol mechanisms, and network performance evaluation indicators. The ability level emphasizes the ability to use routing algorithms and congestion control principles to complete network planning, configuration, and troubleshooting, and has the preliminary network protocol analysis and design ability. The literacy level focuses on engineering ethics, teamwork, and lifelong learning awareness, so that students can comprehensively consider safety, reliability, green, and economy, and make reasonable decisions when facing complex network systems in the future [7].

2.2. Course content and knowledge points

The course revolves around the main line of "protocol layer," and the core modules include: (1) Physical layer: transmission medium, Nessler and Shannon theorem, modulation and coding, Ethernet physical layer standard; (2) Data link layer: framing, error detection (CRC), reliable transmission (stop, etc., GBN, SR), sliding window mechanism, MAC protocols (CSMA/CD, CSMA/CA), Ethernet frame format, VLAN and spanning tree protocol; (3) Network layer: IP addressing (IPv4/IPv6), CIDR, ARP and ICMP, routing algorithm (distance vector, link state, path vector), RIP/OSPF/BGP protocol principle, NAT and tunnel technology; (4) Transport layer: new features of UDP and TCP packet structure, triple handshake and quadruple wave, flow control, congestion control (AIMD, TCP Tahoe/Reno/CUBIC), SCTP and QUIC; (5) Application layer: DNS hierarchy, HTTP/1.1/2/3 evolution, SMTP/POP3/IMAP, FTP and P2P file distribution, CDN caching strategy; (6) Network security-symmetric and asymmetric encryption, SSL/TLS handshake, IPSec and VPN, firewalls and intrusion detection systems; (7) Emerging technologies: SDN control and data plane separation, OpenFlow protocol, NFV network function virtualization, CoAP and

MQTT in the Internet of Things. The above knowledge points include not only the "basic protocol" that must be mastered, but also the "extended protocol" that reflects the technological frontier, which lays a theoretical and engineering foundation for subsequent experiments, course design, and graduation requirements [8].

2.3. Teaching situation and problem analysis

At present, the mode of "large class teaching + verification experiment" is widely used in the teaching of "Computer Network" in colleges and universities. The classroom is mainly explained by a linear PPT. Due to the abstract protocol interaction process, students can only passively accept the concept, and lack the intuitive experience of "how to encapsulate and unencapsulate data packets layer by layer." The experimental part is limited by class hours and equipment, mainly configuring routers and capturing packets to verify TTL changes, and it lacks fault troubleshooting and protocol design training in complex scenarios. The survey shows that about 60% of students say that "all layers of protocols are difficult to connect in isolation," 45% think that "experiments and theory are disconnected," and the scoring rate of routing algorithm comprehensive word problems in the final paper is lower than 55% for three consecutive years. In addition, although there are abundant online resources, MOOC videos and classroom teaching are often simple and repetitive, and do not form complementarities. The update of teaching materials lags behind the development of technology, which leads teachers to temporarily supplement SDN, QUIC, and other new content in the classroom, further compressing the time for interaction and discussion. In general, there is an urgent need for a teaching support tool that can visualize abstract concepts, structure fragmented knowledge, and personalize the learning process, so as to improve students' understanding of the overall working principle of the network and engineering practice ability [9].

3. Knowledge graph and visualization techniques

3.1. Concept and construction method of knowledge graphs

Knowledge graph is a network data structure that uses "entity-relations-attribute" triples as the basic unit and is used to describe the semantic relationships in the objective world. Its core advantage is to support machine-understandable and reasonable knowledge representation. The knowledge graph used in the field of education is usually divided into "domain layer" and "teaching layer." The domain layer describes the course concepts, principles, protocols, and their dependencies, and the teaching layer supplements the learning objectives, difficulty levels, cognitive levels, and links to teaching resources. The construction process can be summarized into five links: (1) Demand analysis: docking the syllabus and graduation requirements index points, clarifying the coverage and granularity of the graph; (2) Knowledge modeling: using ontology engineering method to define classes, attributes and relationships, forming a unified semantic schema; (3) Knowledge acquisition: combining manual annotation, rule extraction and deep learning model to extract entities and relations from textbooks, RFCS, test questions and experimental reports. (4) Knowledge fusion: multi-source heterogeneous data are merged into a consistent graph through entity alignment, conflict resolution, and consistency check. (5) Knowledge update: the version management and incremental update mechanism are introduced, and the continuous evolution of the graph is realized by combining student interaction log and teacher feedback. The final storage mostly uses graph databases (Neo4j, JanusGraph) or RDF triple repositories, supports SPARQL or Cypher queries, and provides high-performance graph algorithm support for upper visualization and intelligent applications [10].

3.2. Classification and characteristics of visualization techniques

Education-oriented knowledge visualization techniques can be roughly divided into three categories: (1) Static concept graph, which displays concepts and their relationships with nodes and edges at once. The structure is clear and easy to print, but it cannot be dynamically screened, which is suitable for a quick overview before class. (2) Interaction force-oriented graph: through D3.js, ECharts, and other libraries, it can zoom, drag, and click drill down, support on-demand highlighting of learning path or protocol interaction process, and can be embedded in web pages and mobile terminals to enhance students' interest in exploring. (3) Temporal and hierarchical view: Sankey diagrams are used to show the cross-layer encapsulation process of data packets, and Gantt charts or time axes are used to describe the change of TCP congestion window with RTT, which helps students to establish "time-space" two-dimensional cognition. In recent years, immersive visualization (WebGL+VR/AR) has been applied to network laboratories, and students can "walk" in the 3D computer room to observe the flow trend. However, limited by hardware cost and development complexity, it is still in the pilot stage. In general, the choice of visualization scheme needs to weigh teaching scenarios, data scale, and user terminals: classroom teaching focuses on intuition and aesthetics, autonomous learning emphasizes interaction and personalization, and collaborative inquiry needs shared annotation and real-time synchronization functions.

3.3. Application status of knowledge graph and visualization technology in the field of education

Universities and MOOC platforms at home and abroad have used knowledge graph for course navigation, intelligent question answering, learning path recommendation, and accurate evaluation. For example, Tsinghua University constructs a graph with 30,000 nodes in the course of "Computer System Foundation," and combines the error mode to trace the concept source of wrong questions. At Zhejiang University, the graph embedding algorithm was used to calculate students' knowledge state, and the accuracy was improved by 12% compared with the traditional IRT model. Commercial systems such as Knewton and ALEKS combine the graph with item response theory to push resources to thousands of people. In the aspect of computer network teaching, MIT converts the protocol state machine into an interactive state diagram, and students click to trigger the message to send and observe the state transition. The University of Munich in Germany bound the SDN topology to the knowledge graph and displayed the corresponding concept explanation in real time when the flow table of the switch was missing. However, there are still three shortcomings in the existing applications. First, the granularity of the graph is coarse, and the details such as protocol fields and algorithm steps are not described enough. Second, visualization is disconnected from teaching. Most of the systems only provide "concept search" or "path display," and do not deeply embed the closed loop of lesson preparation, teaching, experiment, and evaluation. Third, there is a lack of open datasets and toolchains for the Chinese context and in line with the domestic syllabus. Future research needs to focus on the deep integration of "fine-grained domain graph + scene visualization + teaching behavior data," and build a smart teaching ecology covering the whole chain of "teaching, learning, evaluation, and management."

4. "Computer Network" theory course knowledge graph construction

4.1. Build flow

Goal alignment: translate the "theoretical learning goal" of the school syllabus into observable behaviors, such as “dictating the hierarchical role, writing the triple handshake, and calculating the subnet scope.” All subsequent nodes are designed around these three behaviors to avoid excessive modeling. Minimal ontology: only use Excel to establish a three-column table of “concept-relationship-example,” and control the concept column within 200 rows; The relationship column only retains three kinds of “belong to,” “dependent,” and “easy to confuse,” which reduces the maintenance burden of teachers. Corpus acquisition: choose a published textbook and the final examination paper of the past five years in the school to avoid copyright risk; Student teaching assistants use the “boldface + topic stem keywords” method to manually input, and can complete the first version in one week. Conflict resolution: When the same concept is used in many ways, the “words used in the final examination paper” shall prevail to ensure that it is consistent with the assessment. Storage and display: Excel sheets are directly imported into the free online tool “Kumu” to generate interactive concept maps, the links are embedded in PPT, and you can click to enlarge in real time during class. No local server required. Update rhythm: add less than 20 new nodes per semester according to the page error rate to ensure that the graph is “small and lively,” which is in line with the characteristics of rapid flow of teachers and weak technical support in private colleges.

4.2. Knowledge extraction and arrangement

Grading of test points: 180 “examinable concepts” are first defined, and then merged into 60 “high frequency nodes” according to the frequency of appearance at the end of the term. For example, “CSMA/CD, CSMA/CA, token transfer” are merged into “Medium access control” super nodes to reduce the memory burden. Relationship reduction: Only “preorder dependency” and “confusing” edges are retained, and the full picture can be seen by printing on an A4 mind map. Practical attributes: each node adds “textbook page number + real question number,” students can quickly turn to the corresponding content; “Three handshakes, subnet division” is additionally marked with “interview frequently asked questions,” taking into account the demand for job promotion and employment. Bilingual optional: add English abbreviations to key terms (such as TCP, UDP) to meet the needs of some students for postgraduate entrance examination, but do not extend to RFC text to avoid difficulty overload. Review mechanism: the teaching and research team will quickly review the latest test papers in 15 minutes every month to ensure that the new test points are put into the library within a week and keep the map synchronized with the teaching rhythm.

4.3. Visual design

One page of layered diagram: draw five layers of concentric circles with PPT “SmartArt-ring,” only put 6–8 keywords in each ring, and expand the mouse layer by layer in class without an external network. Handshaking animation: Make the three-handshaking process into a 3-frame PPT animation, which can be played step by step, replacing video demonstrations, and solving the problem of an unstable classroom network. Error heatmap: In the final review stage, the teacher manually filled the correct rate of multiple-choice questions into the “conditional format” of Excel and generated a red-green-yellow three-color table. The screenshots were sent to the WeChat group, and students reviewed them according to their needs. No additional development platforms. Paper backup: Reduce the complete concept map to A4 double-sided, print and issue uniformly at the beginning of the semester, and students can write supplementary notes by hand, taking into account the “electronic + paper” double scene. Cost accounting: use the Office suite purchased by the school and free online Kumu throughout, without additional software costs; Update and maintenance only requires Excel operation, which is in line with the reality of tight budgets and weak technical maintenance of private universities. The visualization framework design is specifically shown in **Figure 1**.

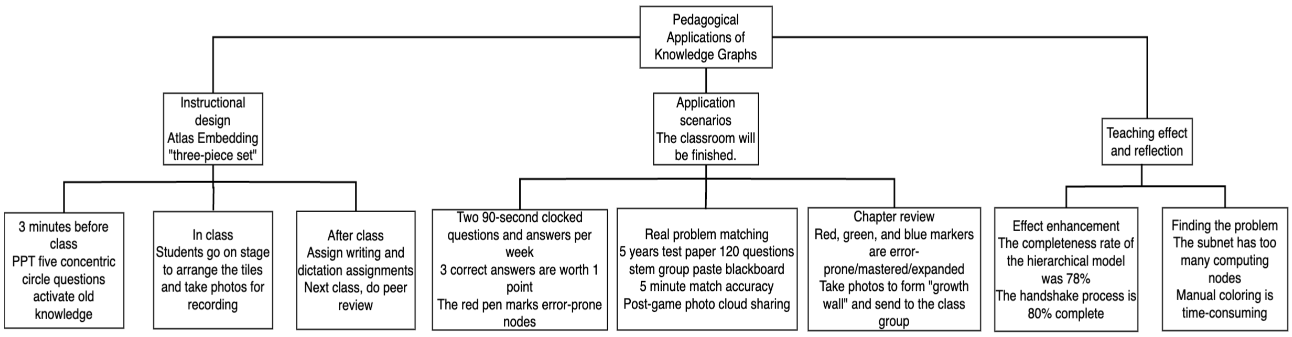

Figure 1. Design of the visualization framework

5. Teaching application of knowledge graph

5.1. Instructional design: Graph embedding "three-piece set"

Three minutes before class, use five-layer concentric circles to ask oral questions to activate old knowledge. In class, let students arrange tiles on the stage and take photos to record. After class, write down oral assignments and evaluate each other at the same table in the next class. Achieving zero computer room can also continue to review the closed loop.

5.2. Application scenarios

Two times a week, 90 seconds of checked-in questions and answers correctly 3 times are worth 1 point, and red pen marks the error-prone nodes. The real question speed match uses the five-year test paper, 120 questions, to paste on the blackboard in groups for 5 minutes. The correct rate of the competition is shared in the cloud after the game. The whole process of zero network zero consumables to form the test point–topic stem–map review package.

5.3. Teaching effect and reflection

After 14 weeks of action research, the students' completion rate of the hierarchical model and handshake process increased to 78% and 80%, respectively. The average of the questionnaire Likert reached 4.3, and the interviews generally recognized that the map helped memory and reduced mind wandering. At the same time, some problems, such as too many subnet calculation nodes and time-consuming manual coloring, were found. In the next step, the concept was simplified and the Excel conditional format was used to automatically generate the heatmap, so as to continuously reduce the maintenance cost and improve the update frequency.

6. Conclusion

In this study, the effectiveness of the "small step, fast walk" knowledge map was verified in the private undergraduate theoretical courses. Only using Excel+ free cloud map increased the accuracy of students' hierarchical handwriting at the end of the term by 30 percentage points, doubled the participation in classroom question and answer, and compressed the time of teachers' lesson preparation by 40%. In the future, it is planned to introduce automatic test capture scripts and Excel plugins to generate one-click heat maps, gradually cover new test points such as IPv6 and SDN, and explore cross-course graph sharing, so as to provide a smart teaching paradigm with zero copyright, zero hardware, and easy to copy for similar colleges and universities.

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