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Research on the Teaching Reconstruction and Practice of Knowledge Graph-Empowered Smart Classrooms—A Case Study of the Linear Algebra Course

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Abstract: ***In response to problems in traditional linear algebra classroom teaching, including linearized knowledge presentation, implicit logical relationships, and delayed feedback on learning conditions, this paper proposes and practices a teaching model empowered by knowledge graphs. Relying on a smart teaching platform, the knowledge graph is transformed from a static teaching resource into a dynamic knowledge navigation system. This paper focuses on the application mechanisms of knowledge graphs across the full teaching chain, including pre-class guided learning, in-class generative teaching, and post-class precise evaluation, and constructs a classroom paradigm of visualized navigation—structured interaction—personalized extension. Teaching practice shows that this model can effectively reduce the cognitive load of abstract concepts, significantly improve students' level of knowledge structuring and classroom participation, and provide a practical path of reference for the substantive implementation of smart courses.***

Keywords: Knowledge Graph, Smart classroom, Linear algebra, Visualization, Educational digitalization.

1. Introduction

With the deepening of digital transformation in education, smart course construction has become an important means of improving teaching quality. As the mathematical foundation of modern engineering technology, linear algebra centers on cultivating students' abstract thinking and logical reasoning abilities. However, traditional classrooms have long been constrained by the one-way output model of definition—theorem—example. Teachers often present knowledge in a linear manner, making it difficult to intuitively reveal the complex network logic among knowledge points, such as the deep relationships between systems of linear equations and vector groups, matrix eigenvalues and systems of differential equations, and quadratic forms and geometric surfaces. This method of knowledge presentation causes students to mechanically memorize formulas without being able to construct a knowledge system, resulting in a low sense of learning achievement and insufficient ability to apply knowledge to solve problems. As a structured semantic network, a knowledge graph connects discrete knowledge points into a visualized knowledge network, offering technical possibilities for addressing the above difficulties. At present, most applications of knowledge graphs still remain at the level of static image display and have not fully realized their value in dynamic guidance and cognitive construction. Deeply integrating knowledge graphs into all aspects of classroom teaching, so that they become assistants for teachers' instructional decision-making and navigators for students' thinking development, is a key point in current smart course construction[1]. Based on this, the course team carried out a smart classroom teaching reform based on knowledge graphs. By using knowledge graph technology to reconstruct the teaching process, and by adopting visualized logical reasoning and interactive classroom participation, the reform realizes a shift from teacher-centered teaching to learner-centered learning.

2. Design Logic of Knowledge Graph-Empowered Smart Classrooms

This study is based on the understanding that a knowledge graph is not only a container of knowledge, but also an engine of thinking. Knowledge graph-empowered smart classrooms are designed from the dimensions of cognition, learning, and evaluation.

2.1 Visualized Navigation in the Cognitive Dimension

Using the graph-structure characteristics of knowledge graphs, abstract algebraic relationships in linear algebra are transformed into visualized[2] nodes (concepts, theorems, and methods) and edges (relationships, derivations, and applications). Through color coding and connection types (for example, solid lines representing derivation and dashed lines representing application), students are helped to grasp the central position of core concepts (such as systems of linear equations and matrix theory) in the entire knowledge network. This promotes the transformation of the learning process from determinants to quadratic forms from a mechanical chapter sequence into an organically connected logical evolution, thereby reducing cognitive load through the visualized navigation of the knowledge graph.

2.2 Dynamic Generation Mechanism in the Learning Dimension

A progressive disclosure strategy is adopted to synchronize the construction process of the knowledge graph with classroom learning. When a new concept is taught, a node is activated or an edge is connected in the graph. Through this dynamic generation process of explaining while connecting, the thinking path of knowledge discovery is simulated, guiding students to follow the teacher's ideas for logical reasoning. Students may also be encouraged to independently explore learning paths, while teachers provide corresponding technical support.

2.3 Data Closed-Loop Feedback in the Evaluation Dimension

Relying on the smart platform, every click, connection, and response made by students on the graph is transformed into learning behavior data. By analyzing students' dwell time, error rates, and path choices at specific nodes, precise learning-condition data are generated to provide a basis for teachers to adjust teaching strategies, forming a data closed loop of teaching—feedback—optimization [3].

3. Teaching Implementation Path of Knowledge Graph-Empowered Smart Classrooms

3.1 Teaching Preparation and Preliminary Diagnosis

The knowledge graph can function as a preview navigation map[4]. Before class, a graph is released that contains only the core conceptual nodes of the lesson and the logical interfaces of related knowledge, without filling in specific details. For example, when learning the similarity diagonalization of matrices, the graph only displays the three nodes of eigenvalues, eigenvectors, and diagonalization, together with the arrow directions. Students then need to try to complete the logical meanings among the nodes according to the preview content. This framework-based preview can encourage students to actively think about the relationships among knowledge points rather than merely being limited to text-based learning. At the same time, the system sets preliminary diagnostic tasks. Students are required to complete simple graph-based connection questions on the platform, generating learning data. The diagnostic reports automatically generated by the background system through these data locate students' cognitive blind spots and help teachers design teaching in a targeted way during lesson preparation, thereby realizing teaching determined by learning.

3.2 Classroom Implementation and Dynamic Interaction

In the classroom teaching implementation stage, the knowledge graph is directly used for course introduction. For example, when explaining vector spaces, the node representing the structure of solutions to systems of linear equations in the graph is highlighted, and questions are used to evoke students' memory of existing knowledge. At the same time, connections are established between old and new knowledge, naturally introducing the concept of vector spaces.

In the teaching of new knowledge and the analysis of difficult points, teachers synchronously activate corresponding knowledge nodes during explanation. For example, in the derivation of Cramer's rule, teachers use dragging and connection operations to dynamically connect determinant properties, algebraic cofactors, and solutions of systems of equations, displaying the logical derivation process of knowledge in real time. This intuitive presentation of an originally implicit thinking process helps reduce the difficulty of understanding abstract proofs. As another example, regarding the teaching difficulties of eigenvalues and eigenvectors, teachers use the hierarchical function of the graph, beginning with the macro-level effect of geometric transformations and gradually moving into micro-level details such as solving characteristic equations and the linear independence of vectors. Through this layered and progressive presentation, students are prevented from experiencing cognitive burden caused by excessive information.

To encourage students to actively participate in the course, group collaborative learning tasks are designed. The whole class is divided into several groups, and each group is responsible for improving a specific branch of the graph. Group members need to supplement that branch with specific examples, mark common error points, and add problem-solving strategies. This process requires students to deeply process and logically reorganize knowledge. Allowing students to personally participate in constructing the knowledge graph can further deepen their understanding and mastery of knowledge.

3.3 Consolidation, Extension, and Dynamic Evaluation

In the post-class stage, the knowledge graph serves as an auxiliary tool for students' personalized learning. Teachers set layered assignments according to the difficulty differences of graph nodes: basic tasks mainly involve filling in core concepts and making connections; advanced tasks require students to sort out the logical derivation paths among nodes; innovative tasks encourage students to combine engineering cases, such as using the graph to analyze matrix transformation paths in image compression, and guide students to extend new application branches for the graph, thereby meeting the learning needs of students at different levels. During final review and the process of identifying and addressing knowledge gaps, students can use the complete course knowledge graph for review. By clicking weak nodes, they can obtain micro-lecture videos, collections of incorrect questions, and extended materials pushed by the system, achieving targeted consolidation. Teachers can quickly identify common knowledge blind spots in the class through background learning data statistics and carry out efficient remedial teaching in a timely manner.

4. Research Process and Effect Analysis

4.1 Research Process

This study adopts the educational action research method and follows the cyclical logic of planning—action— observation —reflection. In the first round of teaching, after the team initially applied the knowledge graph, it was found that excessive information density in the graph easily caused visual fatigue, and that some practical tasks were too difficult, which could trigger students' fear of difficulty. Therefore, targeted optimization was implemented in the second round of teaching. Secondary information was hidden through a collapsible design to reduce visual interference, the difficulty of practical tasks was lowered, guiding scaffolds were added, and diversified evaluation standards were further improved. In this way, a closed-loop improvement mechanism of discovering problems—improving strategies—practicing again was formed.

4.2 Effect Analysis

The teaching effect was comprehensively analyzed through platform logs, questionnaire surveys, and examination scores. The results show that this teaching model has significant advantages. After the implementation of graph-based teaching, the participation rate in classroom interaction exceeded 90%. Especially in the graph co-construction session, students' active speaking time increased, reflecting the effectiveness of the graph in mobilizing students' enthusiasm for participation. At the same time, students' understanding of knowledge became deeper. Final examination statistics show that the score rate for questions involving conceptual understanding improved significantly, indicating that the core advantage of graph-based teaching lies in helping students grasp the essence of knowledge. In addition, students' learning experience also improved markedly. Questionnaire surveys show that 90% of students believed that knowledge graphs helped clarify knowledge threads, and 80% of students stated that the visualized teaching method made the classroom more interesting and could intuitively present the connections among knowledge points, while the graph gave them a clearer grasp of the overall structure of the course.

5. Discussion and Reflection

5.1 The Dual Teaching Positioning of Knowledge Graphs

The role of knowledge graphs in smart classrooms is not only visual presentation, but also a cognitive intermediary connecting teaching and learning. For teachers, the graph is the blueprint of instructional design, requiring a systematic sorting of the knowledge system and thereby reducing arbitrariness in teaching implementation. For students, the graph functions as a cognitive support tool that can transform abstract algebraic symbols into intuitive graphic structures, effectively reducing cognitive load and promoting knowledge internalization.

5.2 Teaching Reflection and Directions for Improvement

Based on reflections from two rounds of action research, although the teaching reform based on knowledge graphs has achieved certain results, continuous optimization is still needed in three dimensions: instructional design, teacher development, and technological ethics. In practice, attention should be paid to preventing excessive graph information density from interfering with learning. Methods such as hierarchical folding can be used to finely regulate the balance between graph presentation and logical clarity. At the same time, it is necessary to emphasize teachers' transition from teaching knowledge to explaining knowledge relationships. In addition, in the face of academic integrity challenges brought about by the popularization of large language models, the proportion of open-ended and inquiry-based tasks should be appropriately increased, guiding students back to deep thinking and thereby using process-based evaluation more effectively to examine their higher-order thinking abilities.

6. Conclusion and Outlook

Relying on the closed-loop design of pre-class navigation—in-class generation—post-class extension, the deep integration of knowledge graphs into course learning not only improves the precision and efficiency of teaching, but also promotes students' transformation from isolated knowledge memorizers into systematic constructors. In the future, the intelligent level of knowledge graphs will be further deepened, adaptive graph recommendation based on learning behavior data[5] will be explored, and the presentation paths and difficulty levels of knowledge graphs will be dynamically adjusted. Cross-course knowledge graph connectivity will also be constructed, and the knowledge mapping between linear algebra and subsequent related courses will be explored, providing students with more comprehensive and coherent knowledge services.

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