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EXPLORATION OF SMART COURSE CONSTRUCTION ON ENGINEERING MATERIALS BASED ON KNOWLEDGE GRAPH

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Abstract: Exploring the path of curriculum development for the transition from digitalization to digital-intelligence is one of the important topics in the field of educational research. Integrated with knowledge graphs and artificial intelligence technology, the curriculum platform would provide new ideas for teachers to conduct blended teaching on subject characteristics. The paper delves into the core concepts of the construction of smart course, and clearly points out that the design of the knowledge graph schema is the cornerstone for smart teaching. It should possess both the universality and the uniqueness for professional fields. Furthermore, taking the Engineering Materials course for mechanical majors as an example, the study explores the practical exploration of smart course construction, including the design of course knowledge maps, optimization of teaching modes, and evaluation systems. The work proposed aims to provide valuable references for the teaching reform of engineering basic courses, and promote the development of intelligent teaching.
Keywords: Smart course; Knowledge graph; Core concept; Blended teaching

1 INTRODUCTION

The acceleration of digital transformation in education is profoundly reshaping the patterns of teaching and learning. As analyzable educational digital resources, Learners' behavioral trajectories, cognitive characteristics, and knowledge states provide precise data support for teaching design and implementation. Currently, blended teaching, which is based on the deep integration of online and offline resources, has become an important direction for curriculum reform in universities. Especially in engineering courses with high-level and complex knowledge systems, exploring the paths for personalized learning and deep cognitive ability cultivation is is particularly urgent. Relying on the smart technology, how to achieve the organic integration of a stable teaching mode and a dynamic teaching process has emerged as a pivotal issue in the engineering education.

The teaching of traditional engineering courses is often confined to a linear and static teaching ecosystem.It limits the enhancement of students' higher-order thinking skills and the satisfaction of their personalized learning needs.In 2004, George Siemens proposed the Connectivism Theory, emphasizing that knowledge resides in network nodes and learning is a process of connecting and constructing networks [1]. The theory provides a philosophical foundation for the application of knowledge graphs in education, and serves as a crucial pillar for novel learning paradigms in the age of artificial intelligence [2]. By constructing a multi-dimensional associative network for knowledge points, course designers not only achieve a dynamic presentation of the knowledge system, but also provide strong support for adaptive adjustment of learning paths. Then, it has laid a technical foundation for creating a teaching model that combines static and dynamic elements.

Taking the *Engineering Materials* course in mechanical engineering as an example, this study explores the construction path of smart course, on the perspective of the design of the course knowledge graph. It proposes a design paradigm centered on the three-dimensional linkage of knowledge-problem-ability (KPA). This paradigm is underpinned by core concepts and knowledge categories, with problem nodes serving as an intermediary bridge and capability development as the ultimate goal. It deeply integrates the knowledge graph with problem-driven learning.

2 KEY CONCEPTS AND THEIR CONNOTATIONS

2.1 Smart Course

Smart Course represents a novel curriculum form that has emerged under the concept of information-based education.

It could achieve dynamic optimization of teaching content, methods, and evaluation, relying on the educational big data and artificial intelligence technology [3,4]. Essentially, Smart Course aims to build a dynamic learning ecosystem, which could enable continuous iteration of the teaching process and provide personalized support.

Compared to traditional courses, Smart Course exhibits distinct sustainable characteristics, as the Table 1. Firstly, it continuously focuses on students' learning processes. By collecting learning behavior data, it dynamically tracks cognitive states and adjusts teaching strategies accordingly. Secondly, it emphasizes the cultivation of higher-order thinking skills. In the curriculum, the core goal of teaching is not the impartation of knowledge, but the cultivation of wisdom, including critical thinking, problem-solving, and decision-making abilities. Thirdly, it closely integrates resource integration technology. The curriculum needs to utilize information technology (such as artificial intelligence, big data, virtual reality et al) as a tool to empower teaching. By constructing a systematic curriculum knowledge graph and integrating digital resources, it supports the planning of personalized learning paths.

Therefore, to construct a smart course, we not only need to clearly distinguish between simply making courses online, but also need to continuously innovate teaching designs based on specific teaching needs. Currently, the teaching of smart courses is mostly conducted through online platforms. Then, we can adopt the blended teaching model, implement problem-based teaching or case teaching, and evaluate learning effectiveness through analyzing learning feedback, thereby continuously improving teaching quality. Additionally, attention must be paid to students' emotional development and value formation in the teaching process.

Table 1 Comparison Between Traditional Courses and Smart Courses

Dimension	Traditional Courses	Smart Courses
Core objective	Transmitting knowledge	Student's Self-Development
Learning content	A linearly developed curriculum knowledge system	Dynamic learning pathways centered around core concepts
Teaching methods	The main forms are lectures and exercises.	Guided by exploration and collaboration
Technical support	Visual teaching resources	Digitized learning ecosystem
Evaluation method	Emphasis is placed on the form of standardized tests and final assessments.	Focus on diversified evaluation, emphasizing process development and capability growth

2.2 Knowledge Graph

A knowledge graph is a technical tool that represents knowledge in a structured and semantic manner. By representing concepts and their interrelationships through nodes and edges, it could construct a knowledge network within the domain. Its core value lies in materializing abstract knowledge systems into interactive and optimized cognitive maps [5,6].

The composition of a knowledge graph primarily includes three elements. The first one is entities. It refers to specific things or abstract concepts that exist independently and can be distinguished. The second one is relationships, which could be used to describe specific connections between entities. And the last one is attributes, which would be used to describe the inherent characteristics of entities. Three basic elements constitute the most fundamental knowledge expression unit, which would be interconnected to construct a semantic network diagram.Constructing a knowledge graph involves not only meticulous discretization of course content, it also crucially entails showcasing the structured, hierarchical, and associative characteristics of knowledge. It aims to establish close connections between factual entities, which lies at the core of cognitive development. Meanwhile, due to issues such as fragmented knowledge content and inadequate ability representation, special attention should be paid to the strong correlation between knowledge, resources, and objectives when constructing a knowledge graph [7].

2.3 Blended Teaching Model

The blended teaching primarily refers to a teaching model that combines the advantages of online instruction with traditional face-to-face teaching. Currently, blended teaching mode has become a mainstream trend in the global education field [8]. It goes beyond merely combining offline and online teaching. Instead, it achieves superior teaching objectives through the integration of the two approaches [9].

The core of blended teaching design lies in integration and reconstruction. On the one hand, integration refers to the technological integration of teaching resources, activities, and assessments. On the other hand, this change in teaching mode inevitably requires a redesign of teaching processes, teacher and student roles, and teaching space arrangements.

3 CURRENT SITUATION AND STRATEGIES FOR THE ENGINEERING MATERIALS COURSE

As a fundamental course in mechanical engineering majors, *Engineering Materials* course aims to cultivate students' decision-making abilities in design material selection and material modification, laying a theoretical foundation for subsequent courses in mechanical design and manufacturing. It is also a crucial aspect in ensuring the quality and safety requirements of mechanical design.

Currently, the course primarily adopts a teaching model combining online resources with offline instruction. However, there are significant deficiencies in course content construction, teaching process implementation, and evaluation system design, failing to achieve deep integration of resource integration and teaching practice. The main goal of continuous course development is to explore effective paths to address the aforementioned issues.

3.1 The Breadth and Depth Characteristics of Course Content Determine that the Design of the Knowledge Graph should focus on Core Concepts

The teaching content of this course presents notable characteristics, specifically reflected as follows:

Firstly, its content encompasses multiple dimensions, including material properties, microstructure, and heat treatment process specifications, etc.It requires not only mastery of basic theoretical principles but also an in-depth understanding of process operation procedures, as well as preliminary analytical skills for engineering applications, making the learning process relatively intense. Students need to master theories, understand technological processes, and also possess preliminary engineering analysis thinking. Limited class hours result in a tight teaching schedule. The theory of the course is largely derived from experimental analysis, which can easily lead to confusion in memory. In addition, the course covers numerous conceptual definitions and a large number of abstract professional terms, making it more difficult to understand.

Secondly, the theoretical calculation part in the curriculum is relatively less, with a greater emphasis on the cultivation of practical abilities. This has also become a challenge in teaching evaluation.

These dual characteristics lead to issues such as fragmented knowledge systems and insufficient depth of understanding among students during the learning process, making it difficult to establish an effective connection between material properties and practical engineering applications.

Knowledge graph technology can facilitate detailed integration of the content of engineering materials courses, laying a crucial foundation for the new reform. However, it is important to note that the construction of the course knowledge graph should closely align with the practical teaching characteristics of the course, with a strong emphasis on the professional training objectives. The core of the knowledge graph for the course should revolve around the correlation between material properties and engineering applications, focusing on the failure analysis, performance requirements, and material selection strategies of typical mechanical components. Its purpose is to establish a mapping path from material properties to practical engineering applications.

By establishing associative relationships between entities, a systematic cognitive chain can be formed, spanning from basic principles to engineering applications, and from microstructure to macroscopic properties. This facilitates students in achieving deep connections and enhancing their ability to transfer and apply knowledge.

Leveraging the hierarchical architecture of knowledge graphs, core elements such as material properties, organizational characteristics, and process methods are structured and associated in the form of nodes. In teaching, it can be further integrated with engineering cases for contextualized teaching presentation, in order to enhance students' analytical and decision-making abilities in real-world engineering problem contexts.

3.2 The Dilemma of the Linear Characteristics in the Teaching Process Urgently Needs to be Addressed by Optimizing the Blended Teaching Model

In traditional teaching practices, due to constraints in class hours and experimental conditions, teachers often advance course teaching in a linear progression manner. They primarily rely on courseware demonstrations and classroom questioning interactions to maintain student engagement, making it difficult to achieve personalized guidance and immediate feedback.

In contrast, through the pre-class online resource push and guidance of self-learning task lists, the blended teaching model could enable students to have a certain knowledge base before entering the classroom. During the class, teachers can concentrate on analyzing key points and difficulties, paying attention to the logical connections between knowledge points. Meanwhile, teachers can also guide students to collaborate in groups around typical engineering cases through problem-driven inquiry activities.

However, it is important to note that teachers should scientifically plan the connection points between online autonomous learning and offline in-depth exploration based on students' cognitive patterns. Based on these connection points, teachers can set stage objectives and evaluation methods for teaching, which is the core of optimizing teaching models.

3.3 The Demand for Competency Assessment Urgently Requires Attention to the Collection and Analysis of Teaching Process Data

In the teaching evaluation process, the current curriculum primarily adopts a model that combines process evaluation with summative evaluation, focusing on assessing students' memorization and understanding of knowledge, but neglecting their ability to apply knowledge to solve practical problems in engineering contexts. A single evaluation dimension makes it difficult to comprehensively grasp students' learning status and high-order thinking development level. Therefore, the collection and analysis of teaching process data has become a crucial aspect of optimizing teaching. Consequently, the gathering and analysis of teaching process data have emerged as a vital step in refining instruction.

In summary, the smart course design of the course should aim to establish a teaching model that integrates both online and offline learning in a coordinated and synergistic manner. Relying on the curriculum knowledge graph, we can achieve digital and intelligent management of the entire teaching process. By deeply integrating online independent exploration with offline interactive discussion, teaching and learning would be bidirectionally reconstructed. The advanced and practical aspects of the course would also be significantly enhanced. These efforts will effectively support the achievement of the comprehensive literacy training objectives for mechanical talents in the context of the new engineering education.

4 THE CONSTRUCTION PATH OF SMART COURSE FOR ENGINEERING MATERIALS

4.1 Set the Anchor Points for Knowledge Graph and Restructure Teaching Contents

Firstly, we should identify the core points of the course and sort out the intrinsic relationship between material composition, process, microstructure, and material properties. Secondly, based on the node association characteristics, the core concepts are coupled in multiple dimensions, such as material composition, microstructural evolution, process parameters, and material property control. Then, all the knowledge points can be categorized into four types, as Fundamental, Transformation, Processing, and Application. As shown in Figure 1, different categories of knowledge points will be matched with corresponding resource types.

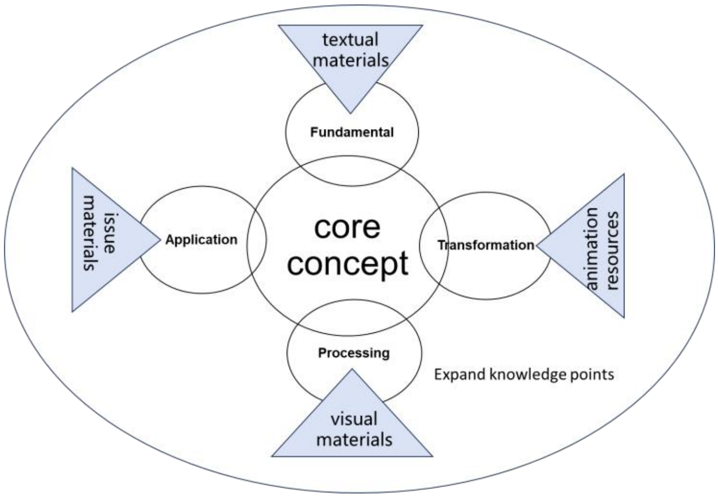

Figure 1 Schematic Diagram of Category Design for Knowledge Graph

In the knowledge graph for this course, 43 core knowledge points were identified and categorized according to the aforementioned four levels. Each core knowledge point is annotated with attributes and is associated with at least two related concept nodes, forming knowledge association links. The entire course generates a total of 304 knowledge nodes, 100 association relationships, and 10 stage questions, achieving a three-dimensional presentation of knowledge. Through the platform's data tracking function, teachers can gather data from various learning stages of course instruction, thereby enabling dynamic monitoring of students' knowledge mastery and cognitive development trajectory.

4.2 Blended Teaching Mode Guided by Reinforcement Questions

Based on the knowledge graph, the course will establish a closed-loop teaching process comprising， including pre-class learning, in-class exploration, and post-class reflection, as shown in Figure 2. Before the class, the teacher defines the scope of learning on the knowledge map. With the help of AI teaching assistants， Students could complete the learning of knowledge points within the defined scope. Dring class, the teacher assigns a discussion task and explains the key knowledge points. Students precisely locate concepts in the knowledge map. Through group collaborative exploration and classroom debate, students' critical thinking skills are trained. After class, students would consolidate their learned content by review and participation in random quizzes. Teachers also guide students to trace back the learning path in the knowledge map and conduct reinforcement training for weak knowledge points with the help of AI teaching assistants. Finally, based on students' learning behaviors and assessment data, teachers would implement periodic teaching evaluations. This process not only guides the implementation of teaching, but also provides information support for the iterative updating of knowledge graph and the improvement of problem chains.

It should be noted that teachers should flexibly adjust the presentation method of the knowledge map and the difficulty level of questions， according the teaching objectives of each stage. Teachers should also adapt their teaching methods based on the specific content of their lessons. For example, during the knowledge construction phase, teachers can pose interpretative questions to assist students in clarifying the logical relationships between concepts. In the knowledge integration stage, teachers should drive cross-node connections with transferable questions to facilitate the mastery of multidimensional knowledge. In addition, to ensure that students achieve deep learning while maintaining a moderate cognitive load, teachers should also pay special attention to the gradient design of tasks and the frequency of group cooperation.

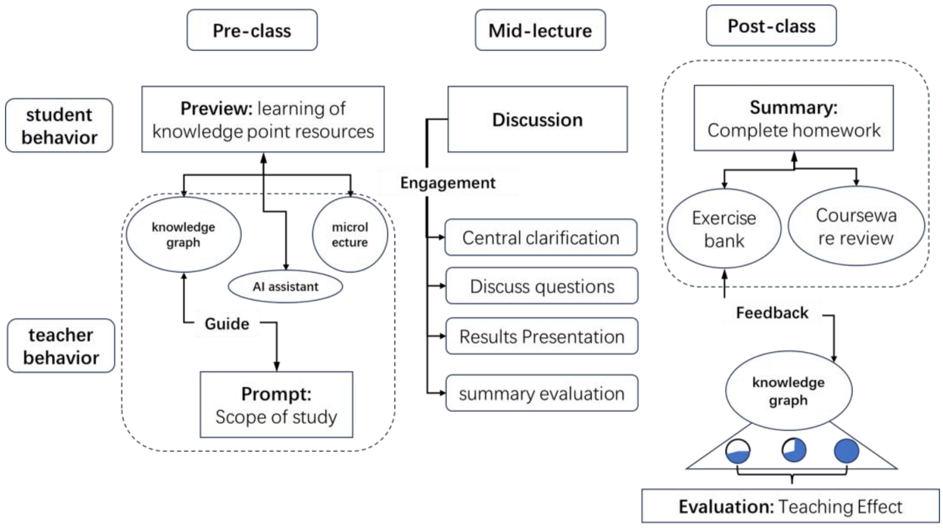

Figure 2 Blended Teaching Mode of *Engineering Materials* course Based on Knowledge Graph

4.3 Establish Diverse Teaching Feedback Pathways to Achieve Competency Assessment

Teaching evaluation encompasses two aspects: the evaluation of students' learning outcomes and the evaluation of teachers' work processes. The former primarily involves a comprehensive assessment based on stage performance, group collaboration, and test scores, while the latter focuses on the entire process of teaching design, implementation, and reflection.

In this course, we design a diversified evaluation index system for students, which is divided into two dimensions: individual behavior and group collaboration. Individual behavior primarily assesses learning ability, encompassing data such as stage tests, online learning duration, discussion participation, mastery rate of knowledge points, test accuracy, and interaction frequency with AI teaching assistants. Group collaboration focuses on assessing analytical skills, encompassing scoring based on the process of evaluating the rationality of task division, contribution within the group, and the effectiveness of collaboration.

The evaluation of teachers relies on changes in stage teaching data, such as the focus of designed questions, the accuracy of student feedback, and the effective use of knowledge map integration in teaching behavior. Combined with teaching reflection logs and classroom observation records, these serve as the basis for improving teachers' teaching methods.

5 CONCLUSION

The smart course provides a new paradigm for teaching and learning in the basic engineering courses of the new era. It not only reconstructs the path of knowledge transfer, but also achieves scientific and refined teaching decision-making by data-driven methods. The teaching of courses in various schools and majors possesses its uniqueness, necessitating that course design closely aligns with the specific needs of professional development and should be rooted in professional training objectives. As the fundamental architecture for constructing intelligent courses, the knowledge graph should possess both general applicability and specialized specificity. Therefore, teachers need to deeply understand the inherent logic of the curriculum knowledge system and continuously optimize the design of graphical nodes and their associated relationships. In curriculum development, teachers should actively adapt to the role transition from knowledge imparters to learning guides and researchers. In the context of the deep integration of technological innovation and education, this transformation will be an inevitable requirement for focusing on distinctive, professional, and practical training objectives.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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