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From Knowledge Presentation to Competency Construction: An Empirical Study on Knowledge Graph and Competition-Education Integration for Enhancing Higher-Order Abilities

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Abstract

Changes in talent cultivation models and teaching demands are driving the innovation of educational philosophies and the transformation of teaching methods. Focusing on the pivotal issue of effectively enhancing college students' higher-order abilities amidst the 'Emerging Engineering Education' and digital transformation initiatives, this study, grounded in the teaching reform of the Operations Research course, constructs a dual-wheel-driven cultivation path centered on 'knowledge graph + competition-education integration.' The knowledge graph facilitates the structured organization of the curriculum's knowledge system, while the integration of competitions creates authentic problem-solving scenarios. This synergy establishes a three-stage progressive cultivation model comprising 'knowledge construction, competency training, and competency transfer.' Teaching experiments reveal that students in the experimental class demonstrated significantly greater improvement than those in the control class across three dimensions: analytical ability, evaluative ability, and creative ability. Furthermore, both the participation and award rates in disciplinary competitions increased substantially. This pathway offers a valuable reference for curriculum reform in similar higher education institutions.

Keywords

Higher-Order Abilities; Knowledge Graph; Integration of Competition and Teaching; Blended Learning.

1. Introduction

The goal of higher education is not merely to equip students with specialized knowledge and fundamental skills, but more importantly, to cultivate their higher-order competencies, encompassing critical thinking, digital and innovative literacy, deep cognitive abilities, complex problem-solving skills, and teamwork capabilities[1]. These competencies are not isolated, diffuse individual attributes; rather, they constitute an integrated whole centered on higher-order thinking. The cultivation of higher-order competencies is a long-term and comprehensive process that requires the synergistic advancement of diverse teaching methods and practical activities. Concurrently, it demands that universities and society jointly provide students with abundant learning resources, a learning environment that stimulates critical reflection, and opportunities that encourage innovation while tolerating failure.

Against this backdrop, higher education must urgently transition from a model dominated by "knowledge transmission" to one rooted in "competency construction," shifting the focus of talent cultivation toward the systematic development of higher-order competencies. Emerging Engineering Education emphasizes enhancing students' innovative awareness and practical abilities through forms such as industry-education integration and the integration of professional education with innovation education, encouraging student participation in research projects, innovation competitions, and entrepreneurial practice. Furthermore, to

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cultivate high-quality engineering and technical talents with distinctive individual characteristics, 3E advocates for personalized educational pathways, allowing students to select customized learning plans based on their own interests.

2. Problem Statement

Currently, the practice of cultivating higher-order competencies in university students continues to face numerous structural and procedural challenges.

(1)At the Curriculum Level: Fragmented Knowledge Structures and Insufficient Capacity for Higher-Order Tasks

The design of many curriculum systems follows the logic of disciplinary knowledge rather than the logic of competency development. Within training programs, the proportion of credit hours allocated to "challenging learning" segments that genuinely carry higher-order competency objectives—such as project-based courses, interdisciplinary integrated design, and in-depth discussions of real-world cases—remains relatively low. The cultivation of higher-order competencies must be anchored in "higher-order tasks." However, most courses still treat "memorization–recitation–simple application" as the terminal point of assessment, resulting in students having few opportunities to experience the complete cognitive development process of "analysis–evaluation–creation."

(2)At the Teaching Method Level: Predominance of Lecture-Based Instruction and Insufficient Exposure of Thinking Processes

Higher-order competencies are difficult to acquire through one-way "listening" alone; they must be actively constructed through "guided practice and reflection" activities. Yet, current classroom instruction has not fully achieved a substantive shift from "teaching-centered" to "learning-centered" paradigms[2]. This is attributable both to the structure of instructors' teaching competencies and to the orientation of evaluative mechanisms. Faculty members at local comprehensive universities often lack systematic training in the "Scholarship of Teaching and Learning," particularly regarding professional guidance on "how to design instructional activities that trigger higher-order thinking." Concurrently, the prevalent institutional tendency to "value research over teaching" in faculty evaluations has led some instructors to lack sufficient intrinsic motivation to invest the substantial effort required to design and implement higher-order teaching strategies such as flipped classrooms, debate-based instruction, and problem-based learning (PBL).

(3)At the Assessment Method Level: Predominance of Summative Assessment and Lack of Process-Oriented Competency Evidence

The design of assessment systems exhibits path dependence. Closed-book final examinations predominantly emphasize knowledge reproduction and formula application. Even when essays or reports are assigned, they often lack clear scoring rubrics for dimensions such as argumentative logic, quality of evidence, and innovative value, thereby rendering it difficult to effectively evaluate students' actual higher-order competencies. "What is assessed" dictates "what is learned." When assessment does not explicitly target higher-order competencies, students' learning engagement naturally deviates from the trajectory of higher-order competency training.

Developing higher-order thinking skills is central to facilitating learner development, and an effective approach involves integrating the cultivation of higher-order thinking with curriculum and instruction to form intended teaching objectives and learning outcomes[3]. Consequently, reforms must be advanced synergistically across four dimensions: reconstructing the curriculum system (incorporating more challenging course content), transforming the teaching paradigm (promoting project-based learning), reforming

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assessment methods (introducing performance-based assessment), and supporting faculty development (providing systematic training in higher-order pedagogy).

3. Effective Pathways for Cultivating Higher-Order Competencies

3.1. Theoretical Foundations

The rapid advancement of artificial intelligence technologies, notably knowledge graphs and deep learning, presents significant opportunities for educational innovation and the transformation of learning approaches. Against the backdrop of Emerging Engineering Education, how to leverage intelligent technologies in conjunction with effective pedagogical strategies to foster the development of students' higher-order competencies has emerged as a focal concern within the field of education.

The "Knowledge Graph + Competition-Education Integration" dual-wheel driving pathway proposed in this study is grounded in the following theoretical foundations:

Cognitive Load Theory posits that human working memory capacity is limited, and excessive extraneous cognitive load impedes learning. Knowledge graphs structurally organize fragmented information, assisting students in constructing a coherent knowledge network. This, in turn, reduces extraneous cognitive load and frees up cognitive resources for engagement in higher-order thinking activities. Thus, the knowledge graph serves as a "cognitive scaffold" and constitutes the structural foundation for the efficient operation of this model.

Situated Learning Theory emphasizes that knowledge is a product of situated activity and that learning should be embedded within authentic problem contexts. Competition-education integration introduces real-world competition problems and evaluation criteria from disciplinary contests, thereby creating learning environments that approximate authentic real-world settings and facilitating the transfer and application of knowledge. Consequently, competition-education integration functions as a "community of practice" and serves as the situational engine that drives competency transformation within this model.

Constructivist Learning Theory asserts that learning is a process through which learners actively construct meaning. Through interaction with the knowledge graph (as a cognitive tool) and exploration of competition tasks (as problem contexts), students actively complete knowledge construction within a cyclical process of "knowledge deconstruction – situated application – reflective reconstruction." The synergy between the knowledge graph and competition integration constitutes the pivotal mechanism enabling the shift from passive reception to active construction.

3.2. The "Dual-Wheel Drive, Three-Stage Progression" Cultivation Pathway Framework

Based on the aforementioned theoretical foundations, a "Dual-Wheel Drive, Three-Stage Progression" pathway for cultivating students' higher-order competencies has been constructed. In this framework, the "Dual Wheels" refer to the two core elements of knowledge graphs and competition-education integration, while the "Three Stages" denote the progressive phases of knowledge construction, competency training, and competency transfer. The essence of the "Dual-Wheel Drive" lies in the synergistic integration of these two elements, rather than their simple superposition. The knowledge graph provides knowledge navigation and competency diagnostics for students participating in competitions; competition tasks, in turn, deepen students' understanding of knowledge and drive the continuous updating and optimization of the knowledge graph. Through the "graph-competition synergy" mechanism and reflective summarization, the practical experience gained from competitions is systematically incorporated into the knowledge graph, ultimately forming a positive feedback

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loop of "knowledge supports tasks – tasks deepen knowledge – reflection enhances competencies." The following section will elaborate on the specific implementation process of this pathway, using the course Operations Research as an illustrative example.

(1)Knowledge Construction – Structured Learning Based on Knowledge Graphs

The objective of the knowledge construction stage is to assist students in establishing a systematic knowledge framework for the course, thereby providing a cognitive foundation for higher-order thinking.

First, the knowledge graph for the Operations Research course is constructed. The knowledge graph is designed with a four-layer structure: "Problem Type – Modeling Method – Solution Algorithm – Application Scenario," covering core modules such as linear programming, integer programming, transportation problems, and graph theory. Concurrently, prerequisite-successor relationships are annotated between knowledge nodes to clarify the sequential order of knowledge acquisition.

Second, multidimensional associations between knowledge nodes are established. These include not only vertical hierarchical associations but also horizontal logical associations (e.g., the relationship between "duality theory" and "sensitivity analysis"), competency mapping associations (each knowledge node is tagged with the corresponding level of higher-order competency), and competition question associations (each knowledge node is linked to past competition problems from previous years).

Finally, the visualization and application of the knowledge graph are realized. Utilizing the knowledge graph functionality of the Chaoxing Fanya Platform, the constructed knowledge graph is made accessible to students. Students can engage in self-directed learning by navigating the graph according to their individual learning needs, while the system intelligently recommends personalized learning resources based on students' click behavior and learning trajectories.

(2)Competency Training–Project-Based Learning Through Competition-Education Integration

The objective of the competency training stage is to cultivate students' abilities in analysis, evaluation, and creation through authentic problem contexts. Specific approaches include:

Pedagogical Transformation of Competition Tasks. Competition problems are stratified into a three-tiered progression: "Basic Edition – Advanced Edition – Competition Edition." The Basic Edition serves as routine course exercises, emphasizing the mastery of fundamental concepts and methods. The Advanced Edition is designated as a group collaborative project, requiring students to complete the entire modeling and solution process using real-world data. The Competition Edition is aligned with the standards of competition submissions, requiring students to develop a comprehensive solution and deliver a public defense.

Pedagogical Embedding of the Competition Process. The entire workflow of "topic selection – modeling – solution – verification – defense" is integrated into the course instruction. Simulated defense sessions are incorporated into the curriculum, with industry mentors or competition judges invited to participate in the evaluation, thereby enabling students to assess their learning outcomes against authentic evaluation criteria.

Curriculum Feedback from Competition Outcomes. Outstanding competition works are transformed into teaching cases, reciprocally enriching and updating the content of the knowledge graph. This establishes a closed loop of "competition problem inclusion – instructional use – student output – new competition problems," ensuring that course content remains closely aligned with the forefront of industry practice.

(3)Competency Transfer – Deepening and Consolidation Through Reflective Iteration

The objective of the competency transfer stage is to achieve the consolidation and transfer of higher-order competencies through reflection and iteration. Specific approaches include: Organizing students to compose "Competency Growth Logs," documenting the thinking

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strategies employed, difficulties encountered, and solutions devised during the problem-solving process, thereby promoting metacognitive reflection on their own thought processes. Conducting "peer review" activities, wherein students are required to critically evaluate the modeling proposals of their peers and propose improvements across dimensions such as the reasonableness of modeling assumptions, the appropriateness of algorithms, and the scope for solution optimization. Guiding students to transform competition outcomes into course design reports or academic papers, thereby facilitating the consolidation and transfer of competencies.

4. Teaching Experiment

4.1. Case Design

To validate the effectiveness of the cultivation pathway proposed above, this study selected the Operations Research course within the Rail Transit Intelligent Operations program at our university as a case study and conducted a one-semester experimental investigation. The research participants comprised two parallel classes: an experimental class (48 students), in which the "Knowledge Graph + Competition-Education Integration" teaching model was implemented, and a control class (38 students), which received traditional lecture-based instruction. No significant differences were observed between the two classes in terms of prior academic foundation or grades in prerequisite courses before the commencement of the study, thereby ensuring the homogeneity of the experimental groups.

4.2. Implementation Process

Knowledge Graph Construction Phase: The project team constructed a knowledge graph encompassing core modules such as linear programming, duality theory, integer programming, transportation problems, dynamic programming, and graph theory. The graph comprises 342 knowledge nodes, 205 resource items, and over 30 authentic competition problems. It was made accessible to students in the experimental class via the Chaoxing Platform. Based on Bloom's Taxonomy of Cognitive Objectives, a Higher-Order Competency Assessment Rubric was developed, incorporating three observable dimensions—analytical ability, evaluative ability, and creative ability—to provide an instrumental foundation for subsequent quantitative evaluation.

Competition-Education Integration Teaching Phase: Instruction was conducted following the "Dual-Wheel Drive, Three-Stage Progression" pathway. The design of the teaching activities aimed to deeply couple the structured navigation function of the knowledge graph with the project-based learning tasks embedded within the competition-education integration framework.

Evaluation and Feedback Phase: Upon conclusion of the teaching experiment, competition entries and course design reports from students in both classes were uniformly collected and scored according to the Higher-Order Competency Assessment Rubric to obtain objective quantitative data. Concurrently, 15 students were randomly selected from the experimental class to participate in semi-structured, in-depth interviews. These interviews aimed to gain deeper insight into students' authentic experiences with the novel teaching model, their subjective perceptions, and concrete manifestations of competency development, thereby supplementing and validating the quantitative findings with qualitative evidence.

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Table 1: Higher-Order Competency Assessment Rubric

Competency Category	Competency Element	Assessment Indicator	Score	Evaluator
Analytical Ability (40%)	Structural Cognition of Knowledge System	Self-directed learning engagement with the knowledge graph	10	Platform Data
	Judgment and Comparison of Algorithm Applicability	Computer-based lab experiments	12	Course Instructor
	Deconstruction and Identification of Model Elements	Classroom performance	18	Course Instructor
Evaluative Ability (30%)	Critical Evaluation Based on Professional Standards	Creation of mind maps for each chapter and course reflections	20	Peer Assessment
	Precise Attribution of Outcome Quality	Homework assignments	20	Instructor Assessment + Self-Assessment
Creative Ability (30%)	Modeling Transfer to Real-World Problems	Group presentations on course optimization plan design	10	Instructor Assessment + Self-Assessment
	Novelty and Originality of Solutions	Level and results of disciplinary competitions	10	External/Societal Evaluation
	Outcome Synthesis and Knowledge Feedback	Level of approved Innovation and Entrepreneurship Training Program projects	10	Institutional Evaluation

4.3. Analysis of Effects

To examine the effectiveness of the pedagogical reform, post-test scores were assessed according to the rubric presented in Table 1 (with a total possible score of 100 points). An independent samples t-test was conducted for analysis. The results indicate a statistically significant difference between the two classes in terms of the improvement of students' higher-order competencies.

Notably, in the dimension of creative ability (with a maximum score of 30 points), the experimental class (24.15 ± 3.06) also demonstrated a significant advantage. Driven by competition-education integration tasks, the competition participation rate in the experimental class reached 86.7%, with 23 awards received at or above the provincial level (compared to 8 awards in the control class). These findings reflect the tangible effectiveness of authentic, challenging contexts in fostering the cultivation of innovative capabilities.

5. Conclusion

Set against the backdrop of the digital transformation of education, this study focuses on the practical dilemmas encountered in cultivating higher-order competencies among students at local comprehensive undergraduate institutions. Based on a systematic review of the

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connotations and evaluation criteria of higher-order competencies, the study proposes a "Knowledge Graph + Competition-Education Integration" dual-wheel driving cultivation pathway and conducts an empirical test using the Operations Research course as a vehicle. The results demonstrate that the knowledge graph assists students in establishing a systematic knowledge structure, thereby providing a cognitive foundation for higher-order thinking. Competition-education integration furnishes authentic and challenging problem contexts, prompting students to engage in the higher-order cognitive states of "analysis–evaluation–creation." The integration of these two elements establishes a positive feedback loop comprising "knowledge construction – competency training – competency transfer."

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