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Construction and Optimization of the Curriculum System for Physics Major in Normal Universities from the Perspective of Knowledge Graphs

Yufei Wei[1], Guoren Yang[1]*, Xingcheng Qin[2]*

[1]Chengdu Normal University, Chengdu 611130, Sichuan, China
[2]The Experimental School Affiliated to Qingyang District Institute of Educational Science, Chengdu 610071, Sichuan, China

**Authors to whom correspondence should be addressed.*

Abstract: Against the dual backdrop of the digital transformation of education and the quality and efficiency improvement of teacher education, the curriculum system for physics major in normal universities is confronted with practical predicaments such as fragmented knowledge, weakened interdisciplinary connections, and disjointed competency cultivation. Based on constructivism theory, connectivism learning theory, and teacher professional development theory, this paper introduces knowledge graph technology and constructs a "three-dimensional integrated" optimization framework for the curriculum system. By sorting out the core competencies and graduation requirements of physics major in normal universities, extracting knowledge nodes, ability nodes, and competency nodes in the curriculum system, and using Neo4j and CiteSpace tools to draw disciplinary knowledge graphs, teaching ability graphs, and interdisciplinary integration graphs, a visualized curriculum correlation network is formed. Taking the 2022 and 2023 grade students of physics major at Chengdu Normal University as the empirical subjects, a comparative study shows that the optimization of the curriculum system from the perspective of knowledge graph can effectively solve the structural defects of traditional curricula, realize the coordinated development of "knowledge-ability-competency," and provide a replicable and promotable practical paradigm for the reform of the curriculum system of science majors in normal universities.

Keywords: Knowledge graph; Physics in normal universities; Curriculum system; Core competencies; Teacher professional development

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1. Introduction

With the in-depth advancement of the construction of "Emerging Engineering Education" and "Emerging Medical Education," basic education has an increasingly urgent demand for innovative physics teachers with a multidisciplinary perspective and digital teaching ability. However, the current curriculum system for physics major in normal universities still has the traditional drawbacks of "emphasizing theory over practice, separate disciplines over integration, and knowledge over ability," which makes it difficult to adapt to the requirements of teacher professional development in the new era. As a core technology of artificial intelligence and data visualization, knowledge graphs have the unique advantages of "correlation, visualization, and structuring." It can clearly present the logical relationships between knowledge nodes and provide technical support for the systematic construction and optimization of the curriculum system. Existing studies have shown that knowledge graphs have significant application value in college curriculum design, teaching resource integration, and personalized learning path planning [1]. Nevertheless, there is a lack of research that takes knowledge graphs as the core tool to systematically and structurally reconstruct the curriculum system, especially the research on realizing the coordinated cultivation of "knowledge-ability-competency," which has become a weak link in current research.

2. Current situation and dilemmas of the curriculum system for physics major in normal universities: An analysis based on talent training programs

2.1. Current situation of the curriculum system

Taking the talent training programs of 2022 and 2023 grades of Physics (Teacher Education) major at Chengdu Normal University as the analysis object [2], its curriculum system covers four modules: general education courses, disciplinary professional courses, teacher education courses, and practical teaching, with the following characteristics:

Complete curriculum structure: The total credits range from 154 to 170, among which disciplinary professional courses account for about 50%, covering core courses such as Mechanics, Thermodynamics, and Electromagnetism; teacher education courses include compulsory and elective courses such as Pedagogy, Psychology, and Middle School Physics Pedagogy; practical teaching links include teaching practice, educational internship, graduation thesis, etc., with a total of 42 weeks.

Clear training objectives: Focusing on the four objectives of "teacher morality cultivation, professional ability, education ability, and development ability," it is decomposed into 8 graduation requirements, forming a support matrix of "objectives-requirements-curricula."

Emphasis on practical ability: A "step-by-step progressive" practical teaching system has been constructed, which gradually improves the teaching practical skills of normal university students from general physics experiments to educational internships.

2.2. Existing practical dilemmas

Severe knowledge fragmentation: Disciplinary professional courses are set according to the disciplinary logic, and there is a lack of clear knowledge correlation design between courses such as Mechanics, Thermodynamics, and Electromagnetism, making it difficult for normal university students to form a systematic disciplinary knowledge network. For example, the "Momentum Theorem" in Theoretical Mechanics lacks teaching correlation with the "Experimental Teaching Design" in Middle School Physics Pedagogy, leading to weak knowledge application ability.

Disjointed ability training: Teacher education courses are separated from disciplinary professional courses, and the cultivation of teaching ability lacks the support of disciplinary knowledge. The talent training program shows that the training of middle school physics classroom teaching ability is only offered in the 6th semester, which is poorly connected with the previous disciplinary knowledge courses, making it difficult for normal university students to transform physics disciplinary knowledge into teaching ability.

Insufficient interdisciplinary integration: Interdisciplinary courses account for less than 4% of the curriculum system, and only a small number of applied practical courses such as C Language Programming and Electrical Engineering are offered. There is a lack of integrated courses of physics with biology, chemistry, information technology, and other disciplines, which makes it difficult to adapt to the demand for interdisciplinary teaching in basic education.

Irrational curriculum sequence: The offering semester of some courses is inconsistent with the knowledge logic. For example, Linear Algebra and Probability and Mathematical Statistics are offered in the 3rd semester, while Theoretical Mechanics, Electrodynamics, and other courses have been offered in the 2nd–3rd semesters, resulting in students lacking the support of necessary mathematical tools and affecting learning effects.

3. Theoretical basis of curriculum system construction from the perspective of knowledge graphs

3.1. Constructivism theory

Constructivism holds that learning is a process in which learners actively construct the meaning of knowledge, emphasizing the situationality and correlation of knowledge [3]. By visually presenting the correlation between knowledge nodes, knowledge graphs provide normal university students with a tool to actively construct a disciplinary knowledge network, which is in line with the constructivist learning concept.

3.2. Teacher professional development theory

Teacher professional development is a coordinated development process of "theoretical knowledge-practical ability-professional literacy" [4]. Knowledge graph can integrate the core elements of teacher professional development, construct an integrated curriculum system of "knowledge-ability-competency," and promote the all-round development of normal university students.

3.3. Curriculum integration theory

Curriculum integration emphasizes breaking disciplinary boundaries and realizing the organic unity of knowledge, skills, and attitudes [5]. Knowledge graph provides a technical tool for curriculum integration, which can clearly present the correlation between different disciplines and courses, and provide support for interdisciplinary curriculum design.

4. Construction path of the curriculum system for physics major in normal universities from the perspective of knowledge graphs

4.1. Extraction of core nodes

Based on the graduation requirements and core courses of the talent training program of physics major at Chengdu Normal University, combined with the professional development needs of middle school physics teachers, the core nodes of the curriculum system are extracted and classified as follows:

Knowledge nodes: Divided into disciplinary basic knowledge nodes and educational theoretical knowledge nodes. Disciplinary basic knowledge nodes include key knowledge points of core courses such as Mechanics, Thermodynamics, and Electromagnetism, e.g., the "Momentum Theorem"; educational theoretical knowledge nodes include core concepts of courses such as Pedagogy, Psychology, and Middle School Physics Pedagogy, e.g., the "Constructivist Teaching View."

Ability nodes: Divided into disciplinary ability nodes and teaching ability nodes. Disciplinary ability nodes include physics experiment operation, logical reasoning, mathematical modeling, etc.; teaching ability nodes include teaching design, classroom implementation, academic evaluation, class management, etc.

Competency nodes: Divided into teacher morality competency nodes, education competency nodes, and development competency nodes. Teacher morality competency nodes include core socialist values, teacher professional ethics, etc.; education competency nodes include moral education infiltration, comprehensive education, etc.; development competency nodes include lifelong learning, reflective innovation, etc.

4.2. Construction process and tools of knowledge graph

4.2.1. Construction process

(1) Data collection: Sort out textbooks, curriculum standards, examination syllabi, and talent training programs of core courses of physics major to extract core nodes; supplement nodes and their correlation relationships through interviews with 10 physics professional teachers and 20 outstanding middle school physics teachers.

(2) Node coding: Encode the extracted knowledge nodes, ability nodes, and competency nodes. For example, "Mechanics - Momentum Theorem" is coded as K1-001, and "Teaching Design - Experimental Course Design" is coded as A2-003.

(3) Definition of correlation relationships: Clarify three types of correlation relationships between nodes—precedence relationship, support relationship, and application relationship.

(4) Graph drawing: Use Neo4j to construct a node correlation database, and draw a visualized graph through CiteSpace to form a disciplinary knowledge graph, a teaching ability graph, and an interdisciplinary integration graph.

4.2.2. Core tools

(1) Neo4j: Used to construct a node correlation database, store knowledge nodes, ability nodes, competency nodes, and their correlation relationships, and support node query and correlation analysis.

(2) CiteSpace: Used to draw a visualized knowledge graph, present the correlation intensity and network structure between nodes, and provide intuitive support for the optimization of the curriculum system.

(3) Wenjuanxing and NVivo: Used for data collection and qualitative analysis in empirical research.

4.3. Construction of three core graphs

From the perspective of knowledge graphs, the construction of a physics curriculum system for teacher education programs can be organized through several interconnected pathways, as shown in **Figure 1**.

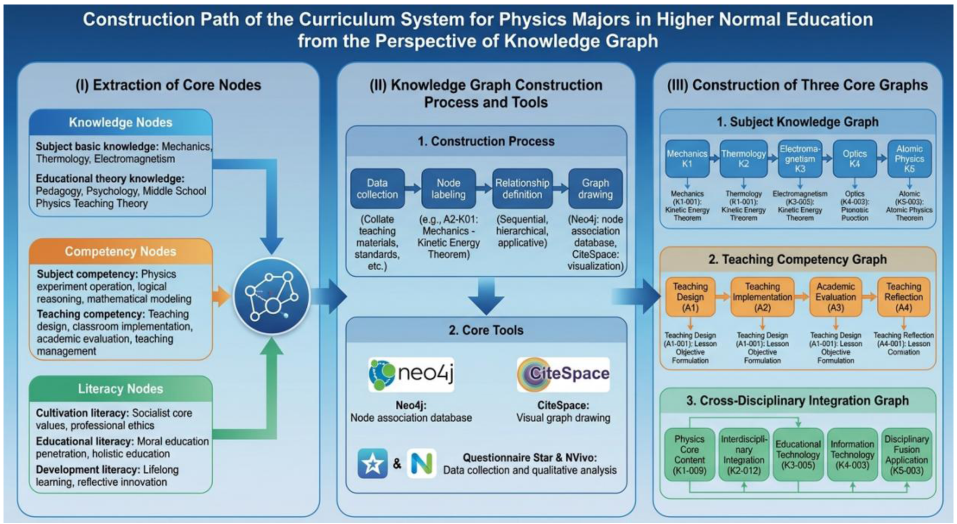

Figure 1. Pathways for constructing a physics curriculum system for teacher education programs from a knowledge graph perspective

4.3.1. Disciplinary knowledge graph

(1) Construction content: Taking the core courses of physics major as the main body, sort out the correlation relationships between disciplinary basic knowledge nodes, form a backbone knowledge network of "Mechanics-Thermodynamics-Electromagnetism-Optics-Atomic Physics," and an advanced knowledge branch of "Theoretical Mechanics-Electrodynamics-Quantum Mechanics."

(2) Correlation example: "Mechanics - Momentum Theorem" (K1-001) has an application correlation with "Electromagnetism - Lorentz Force" (K1-032), a practical correlation with "General Physics Experiment - Momentum Conservation Experiment" (K1-067), and a teaching correlation with "Middle School Physics Curriculum and Pedagogy - Mechanics Experiment Design" (A2-001).

(3) Functional orientation: Provide support for the integration of curriculum content and sequence optimization, and clarify the knowledge connection points between courses.

4.3.2. Teaching ability graph

The construction process of the knowledge graph for teacher education programs is illustrated in **Figure 2**, which demonstrates the connections among teaching ability nodes, knowledge nodes, and competency nodes.

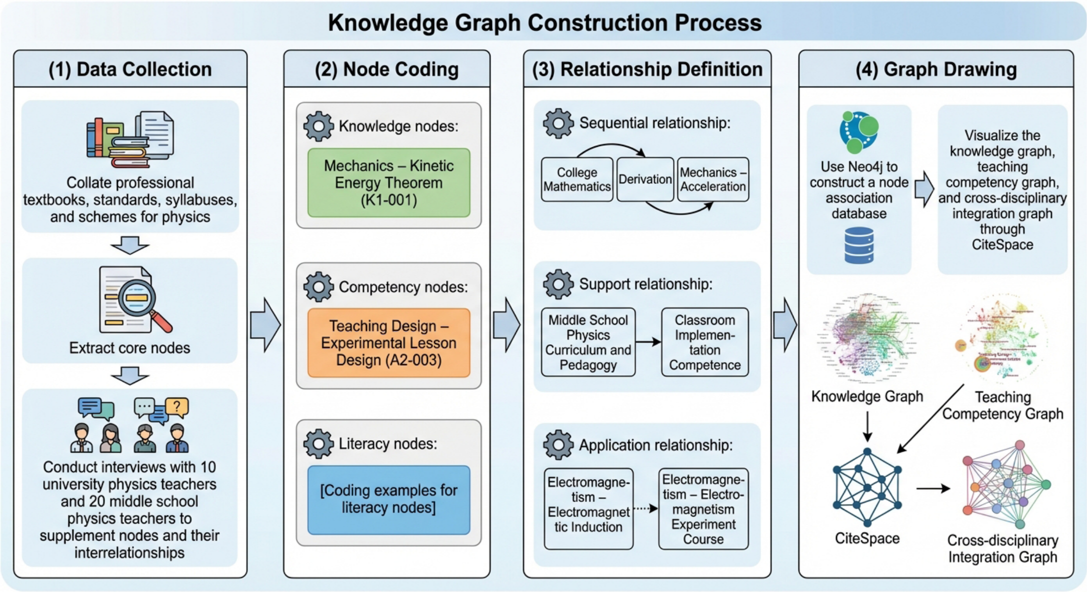

Figure 2. Knowledge graph construction process

(1) Construction content: Taking the development of normal university students' teaching ability as the core, sort out the correlation relationships between teaching ability nodes, knowledge nodes, and competency nodes, and form a teaching ability development chain of "Teaching Design - Classroom Implementation - Academic Evaluation - Reflective Improvement."

(2) Correlation example: "Teaching Design Ability" (A2-001) has a support correlation with "Disciplinary Knowledge - Electromagnetic Induction" (K1-035), an integration correlation with "Competency Node - Education Competency" (S2-002), and a practical correlation with "Practical Link - Teaching Practice" (P1-002).

(3) Functional orientation: Clarify the knowledge support and practical path for the cultivation of teaching ability, and promote the transformation of "knowledge-ability."

4.3.3. Interdisciplinary integration graph

To further promote interdisciplinary integration, a cross-disciplinary knowledge network centered on physics is constructed, as illustrated in **Figure 3**.

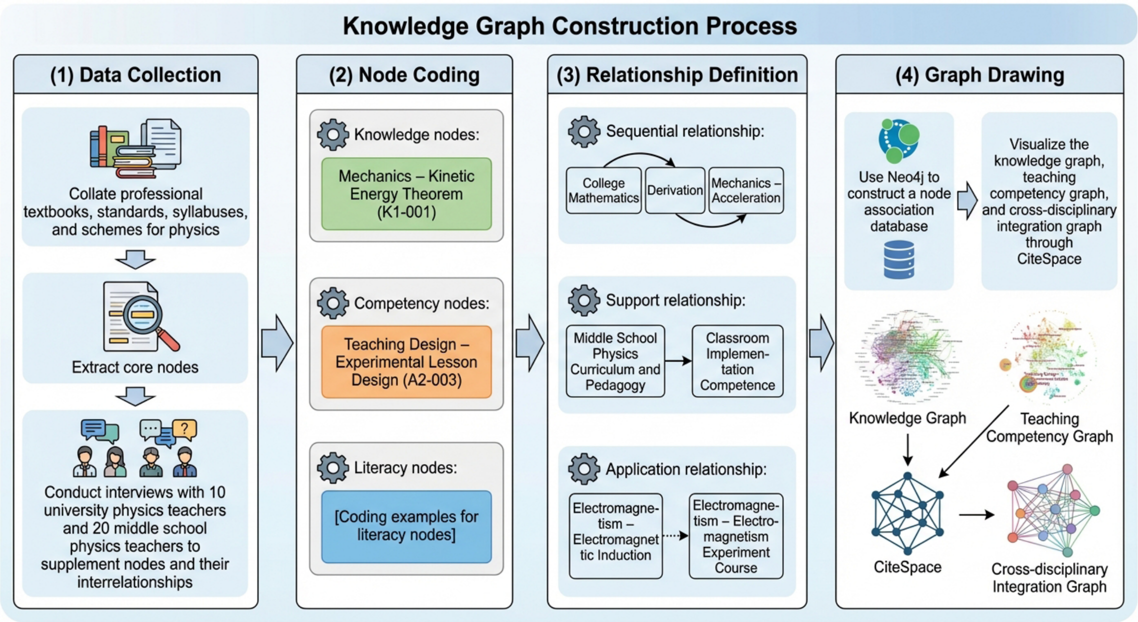

Figure 3. Three core graphs

(1) Construction content: Taking physics as the core, connect the core nodes of biology, chemistry, information technology, mathematics, and other disciplines to form an interdisciplinary correlation network.

(2) Correlation example: "Physics - Optical Tweezers Technology" (K1-089) has an application correlation with "Biology - Cell Manipulation" (K3-012), a technical correlation with "Information Technology - Laser Technology" (K4-005), and a tool correlation with "Mathematics - Vector Operation" (K2-003).

(3) Functional orientation: Provide support for interdisciplinary curriculum design and broaden the multidisciplinary perspective of normal university students.

5. Empirical research and effect analysis

5.1. Empirical objects and design

5.1.1. Empirical objects

Four teaching classes of the 2022 and 2023 grades from the School of Physics and Electronic Engineering of Chengdu Normal University were selected and randomly divided into an experimental class and a control class. The experimental class adopted the curriculum system optimized by knowledge graphs, while the control class adopted the traditional curriculum system.

5.1.2. Empirical cycle

December 2023 to January 2026 (two academic years)

5.1.3. Data collection

Quantitative data: Scores of core courses, scores of teaching skill tests, and scores of the Normal University

Students' Teaching Ability Scale.

Qualitative data: Collected through in-depth interviews, analysis of teaching reflection logs, and feedback from middle school internship schools.

5.2. Empirical results and analysis

5.2.1. Comparison of core course scores

The average score of disciplinary professional courses in the experimental class was 82.3, and that in the control class was 76.5, with a significant difference ($t = 3.24$, $P < 0.01$); the average score of teacher education courses in the experimental class was 84.1, and that in the control class was 78.3, with a significant difference ($t = 2.98$, $P < 0.01$).

5.2.2. Analysis

The curriculum system optimized by knowledge graphs strengthens the correlation between knowledge nodes, helps normal university students form a systematic knowledge network, and improves their knowledge understanding and application.

5.2.3. Comparison of teaching ability test scores

Teaching design ability: The average score of the experimental class was 85.7, and that of the control class was 77.2, with a significant difference ($t = 4.12$, $P < 0.001$); the experimental class got higher scores in the rationality and innovation of knowledge application in teaching design, reflecting the promoting effect of knowledge graphs on the transformation of "knowledge-ability."

Classroom implementation ability: The average score of the experimental class was 83.5, and that of the control class was 76.8, with a significant difference ($t = 3.56$, $P < 0.01$); feedback from middle school internship schools showed that students in the experimental class had better logical coherence in classroom teaching and higher accuracy in knowledge explanation.

5.2.4. Questionnaire survey results

85% of the students in the experimental class thought that "the logical relationship between courses is clear," which was significantly higher than 42% in the control class; 78% of the students in the experimental class thought that "they can quickly transform physics knowledge into teaching ability," while only 35% in the control class held this view.

90% of the students in the experimental class were satisfied with the curriculum system, higher than 62% in the control class, indicating that the optimized curriculum system is more in line with the learning needs of normal university students.

5.2.5. Qualitative analysis results

Interviews showed that students in the experimental class could clearly explain the knowledge correlation between courses, for example, "the momentum theorem is not only a core knowledge point of mechanics, but also a theoretical basis for designing collision experiment courses"; students in the control class were mostly limited to the knowledge memory of a single course and lacked correlative cognition.

Analysis of teaching reflection logs indicated that the reflection of students in the experimental class was more targeted, and they could identify their weak nodes of knowledge and ability based on knowledge graphs, while the reflection of students in the control class was mostly general.

5.3. Research conclusions

Empirical research shows that the optimization of the curriculum system for physics major in normal universities from the perspective of knowledge graph can: strengthen the correlation between knowledge nodes, solve the dilemma of knowledge fragmentation, and improve the mastery level of disciplinary knowledge of normal university students; promote the transformation of "knowledge-ability" and improve the teaching design and classroom implementation ability of normal university students; improve the satisfaction and applicability of the curriculum system, which is in line with the learning and development needs of normal university students; cultivate physics teachers with better systematic thinking, teaching ability and innovative awareness for basic education [6].

6. Conclusion

The construction and optimization of the curriculum system for physics major in normal universities is a core task to improve the quality of teacher education and adapt to the demand of basic education reform [7]. As an important technical tool in the digital era [8], knowledges graph provide an effective path to solve the dilemmas of fragmentation and weakened correlation of the traditional curriculum system. Based on constructivism, connectivism, and other theories, this study constructs a "three-dimensional integrated" optimization framework for the curriculum system of "knowledge-ability-competency." By extracting core nodes, drawing three major graphs, and optimizing the curriculum structure and teaching process, a visualized and systematic curriculum system is formed. Empirical research shows that the optimized curriculum system can effectively strengthen knowledge correlation [9], promote ability transformation, and improve the core competencies of normal university students.

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Disclosure statement

The authors declare no conflict of interest.

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