Cuban Journal of Public and Business Administration
ISSN 2664-0856 RNPS 2458 / Vol. 9 (2025) / e367
Available in: https://apye.esceg.cu/index.php/apye/article/view/367

Original article

DYNAMIC KNOWLEDGE GRAPH-DRIVEN COMPETENCY EVOLUTION FRAMEWORK: AN INTELLIGENT INTEGRATED TRAINING APPROACH TO BRIDGE EDUCATIONAL FRAGMENTATION

MARCO DE EVOLUCIÓN DE COMPETENCIAS IMPULSADO POR GRÁFICOS DE CONOCIMIENTO DINÁMICO: UN ENFOQUE INTEGRADO DE FORMACIÓN INTELIGENTE PARA SUPERAR LA FRAGMENTACIÓN EDUCATIVA

He Chen [I] * https://orcid.org/0000-0001-9354-6974
Ling Chen [I]
Mei E [I]
Lu Cheng [I]
Hongwen He [I]
Fang Deng [I]

[I] Graduate School, Beijing Institute of Technology, Beijing, China
chenhe@bit.edu.cn

* Corresponding author: chenhe@bit.edu.cn

JEL Classification: I21, I25, O33, C63, D83, I28

DOI: https://doi.org/10.5281/zenodo.16949068

Received: 02/07/2025
Accepted: 20/08/2025

Abstract

To tackle issues such as academic system fragmentation, curriculum repetition, and delayed talent development cycle in traditional segmented training, this paper explores the construction of a dynamic knowledge graph-driven "Three-Stage Goal-Oriented" undergraduate-graduate (UG-G) integrated training system. Through literature analysis and empirical research conducted at Beijing Institute of Technology's "Xu Teli Talent Class", the paper proposes a four-dimensional collaborative model encompassing of curriculum, practice, capability and management. The research findings indicate that

Published by the Higher School of State and Government Cadres, Havana, Cuba

Escuela Superior de Cuadros del Estado y del Gobierno

this system, leveraging the cross-stage mapping and intelligent adaptation of knowledge graphs, reduces curriculum repetition rates, enhances student research engagement, and improves the efficiency of translating outcomes into practical applications. This effectively addresses the “capability vacuum” and resource waste issues inherent in segmented education. In the future, the optimization efforts will focus on deepening dynamic capability portrait driven by AI to achieve “one person, one policy” training, increasing participation rates in interdisciplinary virtual teaching and research offices to over 50%, expanding the coverage of digital ideological and political education cases to 70% within three years, and establishing a flexible credit banking system integrated with AI ethics. Meanwhile, the study recommends that educational departments issue technical standards for this integrated training, universities establish cross-departmental collaborative mechanisms, and enterprises co-develop dynamic project pools. A comprehensive evaluation system that integrates ideological and political education with professional development should also be established. This research provides a systematic solution for cultivating national strategic talents and holds significant has important theoretical and practical values for the supply-side reform of higher education.

Keywords: undergraduate-graduate integrated training, dynamic knowledge graph, three-stage goal-oriented, four-dimensional collaboration, talent training system, innovative capability cultivation.

Resumen

Para abordar problemas como la fragmentación del sistema académico, la repetición curricular y el retraso en el desarrollo del talento en la formación segmentada tradicional, este artículo explora la construcción de un sistema dinámico de formación integrada de pregrado y posgrado (UG-G) "orientado a objetivos en tres etapas" basado en gráficos de conocimiento. A través del análisis bibliográfico y la investigación empírica realizada en la "Clase de Talentos Xu Teli" del Instituto Tecnológico de Beijing, el artículo propone un modelo colaborativo de cuatro dimensiones que abarca el currículo, la práctica, la capacidad y la gestión. Los resultados de la investigación indican que este sistema, que aprovecha el mapeo entre etapas y la adaptación inteligente de los gráficos de conocimiento, reduce las tasas de repetición curricular, fomenta la participación de los estudiantes en la investigación y mejora la eficiencia en la traducción de los resultados a aplicaciones prácticas. Esto aborda eficazmente el "vacío de capacidades" y el desperdicio de recursos inherentes a la educación segmentada. En el futuro, los esfuerzos de optimización se centrarán en profundizar el retrato de capacidad dinámica impulsado por IA para lograr la capacitación de "una persona, una política", aumentar las tasas de participación en oficinas virtuales interdisciplinarias de enseñanza e investigación a más del 50%, expandir la cobertura de casos de educación ideológica y política digital al 70% en tres años y establecer un sistema de banca de crédito flexible integrado con la ética de la IA. Mientras tanto, el estudio recomienda que los departamentos educativos emitan estándares técnicos para esta capacitación integrada, que las universidades establezcan mecanismos de colaboración interdepartamental y que las empresas desarrollen conjuntamente grupos de proyectos dinámicos. También debe establecerse un sistema de evaluación integral que integre la educación ideológica y política con el desarrollo profesional. Esta investigación proporciona una solución sistemática para cultivar talentos estratégicos nacionales y tiene importantes valores teóricos y prácticos para la reforma del lado de la oferta de la educación superior.

Palabras clave: formación integrada de pregrado y posgrado, gráfico de conocimiento dinámico, orientado a objetivos en tres etapas, colaboración de cuatro dimensiones, sistema de formación de talentos, cultivo de capacidad innovadora.

Introduction

In the era of the knowledge economy and the intensifying global technological competition, the higher education system is undergoing unprecedented transformational pressure. The World Intellectual Property Organization (WIPO) 2024 report shows that the number of global patent applications in the field of artificial intelligence has increased significantly over the past five years, and the commercialization cycle of quantum computing technology has ~~been~~ greatly shortened. This rapid pace of technological iteration poses a severe challenge to the timeliness of talent cultivation.[1,2] According to the *2023 National Education Development Statistical Bulletin* released by the Ministry of Education, the number of postgraduate students in China has reached 3.8829 million,[3] an increase of 47% compared to 2015. However, the *China Higher Education Quality Report* points out that only about 30% of enterprises believe that college graduates have the ability to solve complex engineering problems, highlighting a structural contradiction between talent cultivation and industry needs, which has become a critical bottleneck constraining innovative development.

The shortcomings of the traditional segmented training model (independent training for undergraduate, master's, and doctoral programs) are evident in three dimensions: the fragmented academic system leads to a discontinuity in ability cultivation. A survey by Beijing Institute of Technology reveals that over 60% of postgraduate students feel that their undergraduate graduation projects have "weak relevance" to their current research topics. The transition from undergraduate experimental skills to postgraduate research and innovation capabilities often requires a lengthy adaptation period, creating a significant "capability vacuum". In contrast, top international universities with integrated training programs enable students to engage in cross-stage research training, significantly reducing the time from entry to publishing their first top-tier journal article compared to traditional models.[4-6] The curriculum system has systematic redundancy. A follow-up survey found that there is considerable content repetition between senior undergraduate and early postgraduate courses in many "Double First-Class" universities in China. The core curriculum for innovation ability, such as *Complex System Modeling* and *Interdisciplinary Research Methodology*, has relatively low coverage rates due to credit limitations in the undergraduate stage. In cutting-edge fields such as chip design and brain-computer interfaces, the technology update cycle has ~~been~~ greatly shortened. However, the traditional segmented education, which can span several years, leads to a growing "graduation to fall behind" problem, where graduates' skills are already outdated by the time they enter the workforce.

Against this backdrop, integrated undergraduate-graduate (UG-G) training has become a strategic national choice to address these challenges. The report of the 20th National Congress of the Communist Party of China explicitly listed "promoting the construction of a high-quality education system" as a core mission for building a strong education nation. The Ministry of Education's *Opinions on Accelerating the Reform and Development of Graduate Education in the New Era* particularly emphasizes "promoting integrated master' and doctoral training and implementing unified training programs".[7] Driven by policies, universities across China have initiated reforms in integrated training: Tsinghua University's Qian Xuesen Mechanics Class" enhances students' opportunities to engage with major technological challenges in advanced fields through a progressive research learning model.[8] Harbin Institute of Technology's "Yongtan Class" has constructed an integrated undergraduate-graduate radar technology training program, significantly improving the efficiency of translating research outcomes compared to traditional model. Beijing Institute of Technology's "Xu Teli Talent Class" has demonstrated through empirical data that integrated training reduces the time from students' initial research engagement to independently publishing SCI papers by approximately 1.5 years, and optimizes course systems to improve resource usage efficiency by 20%.

However, existing research still faces three major limitations: First, it focuses more on institutional design than capability alignment. Most achievements focus on management innovations such as flexible academic systems and credit recognition, but lack research on the transformative mechanism between "knowledge input" and "capability output", with insufficient research on the "knowledge input - ability output" transformation mechanism. Second, the application of technology is limited to data collection. The use of AI in the training process is mainly confined to data collection, with low application rates in intelligent decision support, failing to form a "data-driven - intelligent adaptation" closed loop; Third, the evaluation system lacks a dynamic evolution logic. Most universities still use the number of published papers as the main assessment indicator, with a relatively low proportion of process-based ability evaluation. Based on the wave of digital transformation in education, this paper constructs a dynamic knowledge graph-driven "Three-Stage Goal-Oriented" integrated UG-G training system. By employing graph neural network algorithms to analyze the mapping relationships between knowledge nodes and capability indicators, the framework forms a progressive structure of "foundational capability building - specialized capability enhancement - innovative capability breakthrough".

This paper proposes a four-dimensional synergistic model encompassing dynamic course evolution, practical chain-linking, gradual capability development, and intelligent management feedback loops. Combining reform examples from Beijing Institute of Technology's "Intelligent Unmanned Systems" and other programs, the paper develops an intelligent training solution that integrates cross-stage data mapping. This new approach provides a "technology-empowered - capability-evolving - system-restructuring" paradigm for cultivating top talent in strategic national domains.

Analysis of Integrated Undergraduate-Graduate (UG-G) Training: Concepts and Challenges

(i) Analysis of Integrated UG-G Training

Integrated UG-G training is a systematic educational reconstruction model aimed at breaking down institutional barriers between traditional undergraduate and graduate education, establishing an integrated training system based on the law of capability growth[9]. Its core characteristics are manifested in institutional innovation, continuity of the training process, and dynamics quality assurance.
In terms of institutional design, integrated undergraduate-graduate training achieves structural reform through flexible academic systems, dynamic credit recognition, and collaborative governance

mechanisms. For instance, Beijing Institute of Technology's "Xu Teli Talent Class" employs a flexible academic system of "3+1+X", allowing outstanding students to enter the graduate stage earlier after completing undergraduate basic studies, compressing the traditional 8-10 year segmented training cycle of 8-10 years to 7-8 years. At the same time, relying on dynamic knowledge graphs to construct a credit transfer enables effective alignment of cross-stage courses. For example, the undergraduate course "FPGA Digital System Design" can be evaluated and partially credited towards the graduate course "High-Performance FPGA Digital Processing Technology", reducing repetitive learning by 27%. In addition, the "double mentor system" (academic mentor + industry mentor) and cross-departmental management teams address administrative fragmentation between academic affairs, student affairs, and research departments, significantly enhancing the continuity of research projects.

In the training process, integrated UG-G training emphasizes vertical alignment and horizontal integration, forming a continuous capability development chain. At the vertical level, it constructs a progressive path of "cognitive training → project practice → innovative breakthroughs". Taking BIT's "Intelligent Robot" team as an example, undergraduate students start to participate in foundational scientific research projects (such as robot motion control experiments) in their sophomore year, continuing to national key projects (such as developing algorithms for unmanned system swarms) during their graduate studies. This cohesive training model reduces the formation cycle of system development capability by 1.5 years. At the horizontal level, dynamic knowledge graphs identify interdisciplinary nodes, establishing cross-departmental course modules such as "Intelligent Unmanned System", increasing the number of invention patents of participating students by 40% compared to the traditional model.

In terms of quality assurance, integrated undergraduate-graduate training establishes a set of dynamic monitoring and multiple multidimensional systems. By collecting more than 300 indicators including course grades, project participation, and innovative achievements, it generates a three-dimensional capability radar chart (technical ability, collaboration ability, innovative potential) enabling comprehensive tracking of student growth. The evaluation system breaks away from the "paper-only" tendency, incorporating industry mentor evaluations and weighting the transformation of scientific research achievements. Pilot data from Beijing Institute of Technology shows that this reform improves graduates' engineering practice ability scores by 35%.

From a theoretical perspective, integrated undergraduate-graduate training integrates Trow's educational segmentation theory[10] and Engeström's activity theory,[11] breaking down institutional boundaries and constructing continuous activity systems that transform discrete educational stages into a continuous spectrum of capability evolution. Its core innovation lies in prioritizing students' capability development, achieving seamless connection between knowledge learning, scientific research training, and innovative practice.

(ii) Analysis of Existing Problems and Deep-seated Conflicts

The current implementation of integrated undergraduate-graduate training model still faces multiple structural challenges, with the root of these conflicts stemming from the interactive relationship between the education system's internal and external elements. From the perspective of the educational process, the fragmentation of the training system is evident. In terms of course settings, there is a significant overlap in knowledge between the senior undergraduate and early graduate stages, yet critical transitional courses are generally lacking, leading to cognitive discontinuity for students during this phase.[12] In research training, undergraduate graduation projects often lack continuity with graduate research directions, prolonging students' research adaptation period. In terms of management systems, most universities still maintain a binary division between undergraduate and graduate training, creating institutional barriers in credit recognition and resource allocation.[13]

Imbalances in resource allocation further constrain the effectiveness of integrated training. Hardware facilities exhibit distinct stage-specific usage patterns, with undergraduate teaching resources contrasting sharply with strained graduate scientific research resources. In faculty allocation, the guidance efforts of mentors are unevenly distributed across different educational stages, limiting undergraduates' opportunities for scientific research guidance. The fragmented state of digital management platforms exacerbates this problem, as cross-stage data-sharing mechanisms are not yet established, hindering the continuity of the training process.

The quality assurance system has not yet adapted to the demands of integrated training. The lack of a dynamic adjustment mechanism makes it difficult for training programs to be flexibly optimized according to individual student differences. Evaluation standards still heavily emphasize traditional academic output, with insufficient attention given to the process-based evaluation of students' cross-stage ability development. In addition, the integration of value-based education with professional training remains superficial, failing to achieve an organic unity of knowledge teaching and value guidance.

These conflicts essentially reflect the profound tension between the segmented education paradigm formed during the industrial era and the demand for innovative talent in the knowledge economy. The traditional training model is built on the logic of disciplinary division, while contemporary scientific and technological innovation requires interdisciplinary integration that transcends established boundaries. The hierarchical management system and single evaluation standards further entrench reform resistance. Addressing these conflicts requires promoting systematic change from the perspective of educational ecology reconstruction.[14,15]

(iii) Breakthroughs and Bottlenecks in BIT's Reform Practice

Beijing Institute of Technology has constructed a "three-stage progressive" scientific research training system for its integrated undergraduate-graduate program, forming a systematic capability development framework. In the first year, students participate in disciplinary cognition training activities to organize their professional knowledge and build a core foundational cognitive framework. During the second and third years, project-based learning is promoted, with many students engaging in scientific research training programs that integrate multidisciplinary knowledge and enhance application capabilities in practice. From the fourth year through the graduate stage, the focus shifts to innovative breakthroughs, with some scientific research results achieving industrial transformation.[9] In terms of management innovation, the developed intelligent management platform has achieved multidimensional breakthroughs: the academic early warning system establishes a dynamic warning model by analyzing students' learning data, which improves the accuracy; the mentor dual-selection system, optimized using knowledge graph technology, has increased satisfaction; and the resource scheduling platform integrates various scientific research resources through intelligent scheduling algorithms, significantly improving usage efficiency.

However, the reform process still faces deep-seated constraints. The cross-departmental course selection is hindered by different institutional standards, leading to integration barriers; The vertical scientific research teams struggle with interdisciplinary collaboration, limiting the depth of integrated training; The application of artificial intelligence technology in the training process remains focused on data collection, failing to fully leverage intelligent decision-making support; and the evaluation system overemphasizes outcome-oriented assessment, with insufficient focus on process-based capability evaluation. In order to overcome these challenges, Beijing Institute of Technology is promoting institutional innovations, constructing a cross-departmental course credit recognition mechanism, developing a knowledge graph-based team collaboration support system, deepening the application of artificial intelligence technology in path planning for capability development, and improving a multidimensional evaluation system that balances foundational basic capabilities, innovative potential, and ethical literacy. These explorations provide a reference practice paradigm for integrated talent training in engineering universities.

Four-dimensional Collaborative Framework for Integrated Undergraduate-Graduate Training

(i) Theoretical Framework

Building on the demand for cultivating first-class innovators in the new era, Beijing Institute of Technology has developed a novel integrated Undergraduate-Graduate (UG-G) training system based on "three-stage goal-oriented" dynamic knowledge graphs through long-term educational and teaching reform. The system, illustrated in **Figure 1**, is centered around a dynamic knowledge graph and driven by three-stage goals of strengthening the foundation of basic abilities, reinforcing professional capabilities, and achieving breakthroughs in innovative abilities. The framework integrates the elements such as curriculum, practice, and evaluation, breaks the barriers of traditional segmented training, and forms a closed-loop training model of "goal orientation - graph support - dynamic optimization".

1. Three-stage Goal-oriented System

Strengthen the Foundation of Basic Ability Goal (Junior Undergraduate Stage): Focuses on constructing a professional basic knowledge system and cultivating basic scientific research skills. Supported by dynamic knowledge graphs, the system systematically organizes core knowledge points required in the early undergraduate stage, forming a structured knowledge network. Through course learning and basic experimental projects, students are required to master basic scientific research skills such as literature retrieval, experimental design, and preliminary data analysis. These skills serve as a solid foundation for subsequent capability development. The achievement degree of this stage is evaluated through multiple dimensions such as knowledge tests and the quality of experimental reports, with feedback incorporated into the dynamic knowledge graph to optimize the subsequent training path.

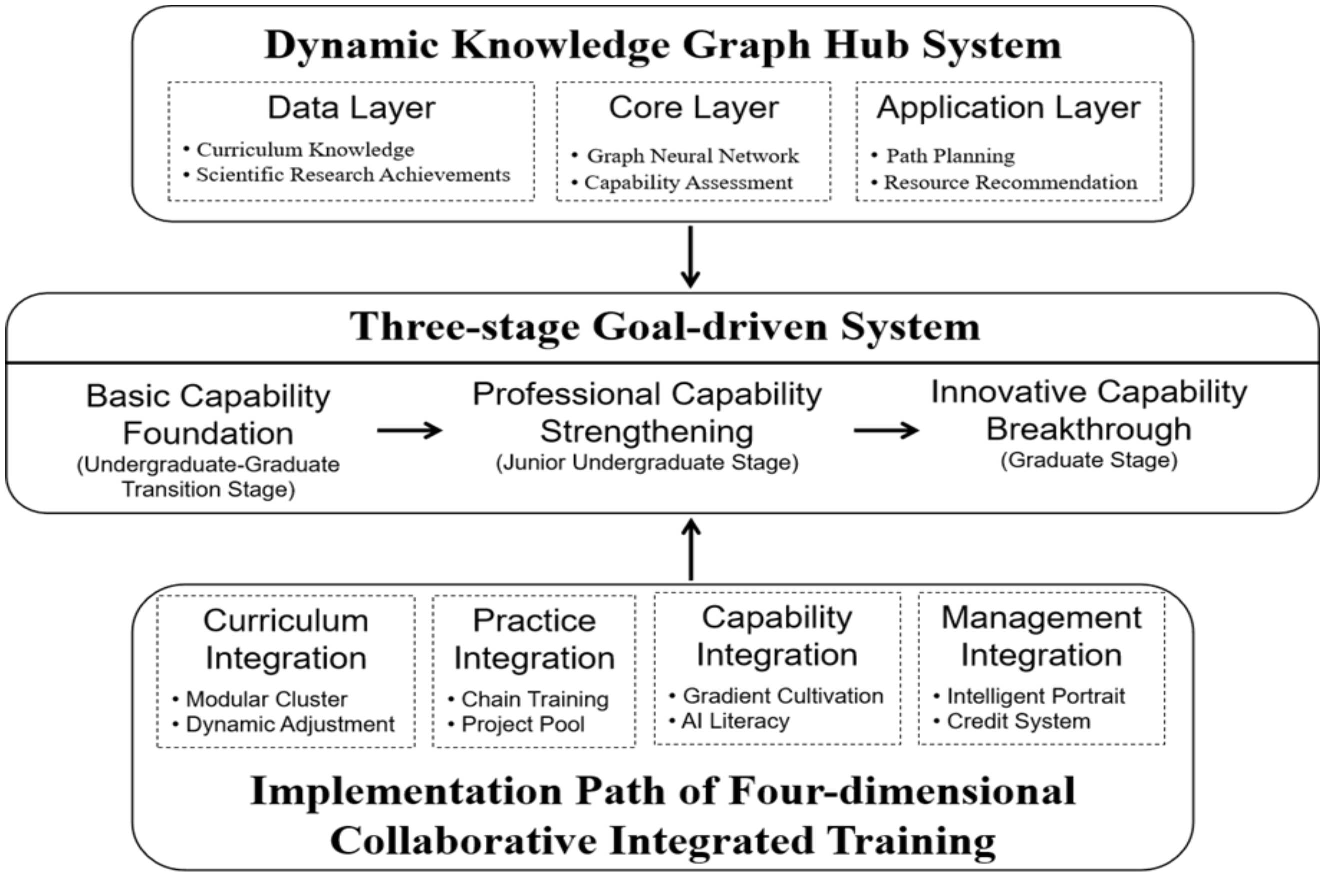

Figure 1. Three-stage Goal-Oriented Integrated Undergraduate-Graduate Training System Based on Dynamic Knowledge Graph
Source: own elaboration

Reinforce Professional Capability Goal (Senior Undergraduate - Early Master's Stage): Focuses on deepening professional core knowledge and enhancing independent research capabilities. The dynamic knowledge graph updates advanced specialized knowledge nodes based on disciplinary development and industry needs, incorporating topics such as deep learning algorithms and multi-agent collaborative control, and establish associations with foundational undergraduate knowledge. In this stage, students participate in mentor-led projects and industry initiatives, applying professional knowledge to solve complex problems in practice, and gradually developing the ability to design projects independently and carry out experimental research. At the same time, through interdisciplinary course learning and project collaboration, students integrate knowledge and broaden their professional horizons. The knowledge graph tracks students' learning progress and capability development in real time, and dynamically adjusting course recommendations and matching practical projects.

Achieve Breakthroughs in Innovative Ability Goal (Late Master's - Doctoral Stage): Aims to cultivate students' original innovation capabilities and the ability to transform scientific research achievements into practical applications focusing on academic frontiers and major technological challenges. The dynamic knowledge graph concentrates on international hot academic topics and national strategic needs, introducing advanced knowledge from fields such as national defense and civil affairs, and guides students to conduct forward-looking and groundbreaking research. At this stage, students need to independently undertake scientific research projects, explore new theories, methods, and technologies, and promote the transformation of scientific research achievements into practical applications. The knowledge graph analyzes data from students' research papers, patents, and project reports to deeply evaluate their innovation capabilities recommending interdisciplinary collaboration resources and international academic exchange opportunities to support innovative breakthroughs.

2. Core Support Architecture of Dynamic Knowledge Graph

As the technical hub of the integrated undergraduate-graduate training system, the dynamic knowledge graph constructs a dynamic and multidimensional knowledge network by integrating data from various sources such as disciplinary knowledge systems, industry technical standards, teaching resources, and student learning behaviours. Its core architecture can be analysed in three layers: data layer, model layer, and application layer.

In the data layer the dynamic knowledge graph creates a "digital twin" of the educational knowledge system by integrating multi-source data. On the one hand, the system organizes the curriculum knowledge from the undergraduate to graduate stage, breaking down each course into computable knowledge nodes. For example, the course Automatic Control Principles is divided into basic nodes such as "PID control algorithm" and "root locus method", with each node tagged with labels like "course affiliation - difficulty level - capability orientation", forming a structured knowledge network.

On the other hand, the system collects student learning behaviour data, including course assignments, experimental reports, scientific research project records, using natural language processing technology to analyze the capability performance data contained within. In practice, this data layer can integrate thousands of undergraduate-graduate course knowledge nodes with a large number of student learning trajectory data, providing a solid data foundation for capability mapping.

The model layer is the intelligent core of the dynamic knowledge graph, utilizing graph neural network algorithms to achieve precise mapping between knowledge nodes and capability indicators. Its working principle is similar to an intelligent navigation system for "knowledge - capability" mapping. The graph neural network employs a ternary structure of "node - edge - graph": knowledge points and capability indicators serve as independent nodes, with the strength of the associations between nodes acting as edges, calculated by algorithms to determine the contribution weight of knowledge points to capability indicators. For example, by analysing the research data of excellent graduates, the algorithm finds that the knowledge node of "probabilistic graph model" has a high correlation with "AI algorithm design capability", indicating that this knowledge point plays a crucial role in capability development. This mapping mechanism resembles the brain's associative thinking - when the system identifies that students need to improve a certain professional capability, it will automatically associate relevant knowledge nodes and plans the learning pathway. In practice, the graph neural network model has realized dynamic mapping of numerous knowledge nodes with core capability indicators, significantly enhancing the transformation efficiency of "knowledge - capability".

In the application layer, the dynamic knowledge graph transforms the algorithm analysis results into operable educational tools, forming an intelligent closed loop of “diagnosis - recommendation - optimization”. In terms of capability diagnosis, the system generates a three-dimensional capability portrait based on students’ knowledge mastery data. When a certain capability dimension is insufficient, the graph automatically recommends highly correlated knowledge nodes as complementary pathway, with a high recommendation accuracy. In terms of curriculum optimization, the graph identifies repeated contents through cross-stage knowledge mapping and suggests transforming repetitive nodes into “capability improvement” advanced contents, significantly reducing the repetition rate of related courses.

In addition, the application layer also supports scientific research project recommendation by analyzing the students’ knowledge graph and the project’s capability requirements, achieving precise matching between topics and students’ capabilities, and significantly improving project continuity.

This architecture follows the logic of “data layer foundation - model layer intelligence - application layer implementation”, deeply integrating graph neural network algorithms with educational scenarios. It not only retains the technological core but also reduces the understanding barrier through educational metaphors, finally achieving precise guidance from “knowledge input” to “capability evolution”. Practices show that the training program based on this architecture has significantly shortened the period from students’ initial research engagement to publish their first high-level paper, verifying the technical value of dynamic knowledge graph in capability cultivation.

3. Establish Support Mechanisms

Establish a cross-departmental integrated undergraduate-graduate training leadership group to coordinate the work of academic affairs, scientific research, and human resource departments, breaking down management barriers and fostering a collaborative education ecosystem. The leadership group, based on three-stage goals and dynamic knowledge graph analysis results, formulates unified training policies and resource allocation plans, periodically evaluates training effects and makes dynamic adjustments.

Build a multi-faceted resource guarantee system that combines “virtual and real-world elements, along with school-enterprise collaboration”, introducing real-world industry projects into practical teaching to improve students’ professional abilities in real engineering environments. In terms of faculty resources, implement a “three-mentor system” assigning academic mentors, industry mentors, and ideological and political mentors to give guidance and support from different dimensions.

Establish a whole-process quality evaluation system based on the dynamic knowledge graph to comprehensively evaluate students from multiple dimensions such as knowledge mastery, ability development, and goal achievement. The evaluation content includes not only traditional exam scores but also scientific research project achievements, practical performance, and innovative thinking. Evaluation data is fed back to the dynamic knowledge graph in real time to optimize training programs and adjust students’ personalized learning paths. At the same time, the training system itself undergoes periodic evaluations to analyze the effectiveness and existing problems of each component, and continuously improve and refine the training system to ensure the quality of talent cultivation training.

(ii) Deepened Design and Implementation Path of Four-dimensional Collaborative Integrated Training

1. Curriculum Integration: Three-Stage Curriculum Evolution System Driven by Dynamic Knowledge Graph

The core breakthrough in integrated-undergraduate-graduate training lies in the systematic reconstruction of the curriculum system. Based on dynamic knowledge graph technology, we have constructed a three-stage curriculum cluster of "foundational - frontier - interdisciplinary", achieving the paradigm shift from knowledge teaching to capability cultivation. In the early undergraduate stage, the system focuses on the cultivation of core literacy such as mathematical foundation and programming ability. Through topological analysis of the knowledge graph, key knowledge points in courses like linear algebra and Python programming are constructed into an extensible network. For instance, Beijing Institute of Technology's School of Computer Science, this stage sets up a foundation module with core courses, where the knowledge points of each course are mapped to the professional courses of the graduate stage, ensuring that more than 30% of the teaching content has vertical continuity.

The undergraduate-graduate stage demonstrates the real-time adaptive advantages of the dynamic knowledge graph. Each semester, the system automatically retrieves cutting-edge literature from databases such as IEEE and ACM, using natural language processing technology identify trends in the field. For example, when detecting breakthroughs in generative AI technology with machine learning, the system promptly adds new teaching units on diffusion model principles and applications to the "Machine Learning Applications" course, simultaneously updating the experimental project library. This dynamic update mechanism keeps the curriculum content aligned with technological development. Pilot data shows that students participating in this model adapt to new technologies 40% faster upon entering graduate school.

The interdisciplinary innovation module at the graduate stage is the top-level design of the curriculum system. Through interdisciplinary correlation analysis of the knowledge graph, the system identifies intersections between artificial intelligence and fields like aerospace and materials, developing interdisciplinary courses such as AI + Aerospace and Intelligent Material Design. These courses adopt a "dual-mentor system" (academic mentor + industry mentor) and project-embedded teaching, requiring students to integrate multidisciplinary knowledge while solving real-world engineering problems. Notably, the system analyzes the capability development trajectories of outstanding graduates over the years to establish an interdisciplinary innovation capability evaluation model, providing data support for course optimization.

The intelligent intervention mechanism of the learning behavior analysis platform ensures ~~is~~ the quality of curriculum integration. The platform constructs a personalized learning early warning system through multi-modal data collection (including classroom interaction, online tests, and experimental operations). When detecting students' mastery of key chapters, such as convolutional neural networks, falls below at threshold, the system will initiate a three-level intervention: the first level pushes intensive micro-courses and targeted exercises; the second level matches peer tutoring resources; and the third level triggers one-on-one teacher guidance. This hierarchical intervention system improves the efficiency of students' knowledge weakness by 3.2 times, achieving a curriculum satisfaction score of 92.7 (compared to 81.5 in traditional models).

2. Integrated Practice: Dual Circulation Training Mechanism of Vertical Chain and School-Enterprise Collaboration

The innovative design of the practical teaching system breaks down the fragmentation of the traditional training model where “undergraduates focus on basics and graduates focus on innovation”. BIT has constructed a vertical chain practice system with three distinct stages: in the undergraduate stage (grades 1-3), students experience progressive training from cognition to participation. Freshmen are introduced to basic experimental equipment through laboratory open days; Sophomores participate in URP projects (such as basic robot motion control); Juniors engage in sub-module research of the mentor-led projects, (such as SLAM algorithm optimization). The knowledge graph, by analyzing over 2000 historical cases, establishes a practice project difficulty coefficient model , ensuring optimal difficulty progression (around 35% increase) across these stages.

Dual Circulation Training Mechanism of School-Enterprise Collaboration deeply integrates industrial demands into the training process. The dynamic project pool, co-constructed with enterprises such as Huawei and China Aerospace Science and Industry Corporation， has three innovative features: The first is hierarchical setting. Undergraduates participate in basic work such as data labeling, master’s students develop algorithm module, and doctoral students lead system-level innovation; The second is dynamic update. Enterprises submit their latest technical requirements every quarterly, which, after evaluation by the college academic committee, are transformed into teaching projects; The third is achievement feedback. Students’ research achievements are incorporated into the knowledge graph’s cases after enterprise validation. In the “Autonomous Driving Scene Recognition” project, the cross-grade team of integrated undergraduate and graduate students collaborated on the entire process from data labeling to model deployment, resulting in achievements adopted by the enterprise and applied for 3 patents.

The quality control in practice training relies on a multidimensional evaluation system. The system collects experimental operation data through wearable devices, uses computer vision to analyze the team collaboration process, and generates a comprehensive practice capability report combined with indicators such as the technical innovation and completion degree of project achievements. Data shows that students in this model score 28 percentage points higher in engineering implementation capability (according to IEEE standards) than those in traditional training model.

3. Capability Integration: Stage-by-stage Infiltration System of Gradual Cultivation and AI Literacy

The cultivation of innovative talents must follow the inherent laws of capability development. The designed “innovative thinking - method training - breakthrough research” gradual cultivation system uses the knowledge graph’s capability development trajectory prediction for precise stage adaptation. The undergraduate stage focuses on stimulating innovative awareness through projects such as intelligent campus workshops, requiring students to propose technical solutions for real-world scenarios (e.g., library management, energy monitoring). The system will record the process of students' creative generation and analyze their thinking characteristics for future reference.

Graduate Stage emphasizes systematic construction of research paradigms, offering courses in research methodology, including critical literature review, experimental design optimization, and academic ethics. Each module is associated with typical research cases in knowledge graph. The system evaluates students' research logic and data processing methods in real time during virtual simulation projects, expediting the publication of their first SCI paper.

The cultivation of AI literacy adopts a three-dimensional infiltration strategy of "technical capability - ethical awareness - application innovation". The undergraduate stage cultivates students' technical awareness through "AI+X" courses; The undergraduate-graduate transition stage offers ethical courses on algorithm interpretability and data bias detection; The doctoral stage needs to complete practical projects like AI military application ethics assessment. The knowledge graph will track students' decision-making processes in scenarios such as autonomous driving ethical dilemma, assessing their techno-ethical development.

4. Integrated Management: Closed-loop System of Cross-stage Evaluation Driven by Intelligent Portrait

The "intelligent portrait + cross-stage evaluation" mechanism integrates multi-source data from academic affairs, scientific research, and practice through the knowledge graph. The system generates a dynamic capability portrait using graph neural network algorithms. For example, if a student's control system design capability is identified as 0.82 but the interdisciplinary collaboration capability is only 0.56, the system automatically recommends the cross-departmental project like "Intelligent Unmanned System", which includes multidisciplinary collaboration in "mechanical design - algorithm development - testing verification".

The growth path planning function, based on the knowledge graph's deduction algorithm, strengthens academic-oriented students' "theoretical derivation - paper writing" knowledge chain (e.g. recommending advanced optimal control theory courses), and engineering-oriented students' "system integration - experimental debugging" capability module (e.g. pushing embedded system development practice projects), improving the student-goal matching from 58% to 85%.

The innovative scientific research credit system quantifies training effectiveness. The system transforms academic achievements into standard credits, which are not only used for both merit-based rewards but also analyze the correlation between achievements through the knowledge graph. Data shows that students with high credits often form a clear technological evolution chain, verifying the continuity of training. The cross-departmental collaboration platform solves the problem of management fragmentation. Built on block chain technology, the distributed management system enables real-time data sharing across academic affairs, student affairs, and scientific research departments, reducing the cross-departmental approval time from 15 to 3 working days and achieving 100% digital coverage of student training files, forming a full-process integration from course selection to achievement transformation.

The greatest value of this management system lies in forming a closed loop of "monitoring - evaluation - optimization". The system generates a training quality report every month, analyzing the input-output ratio of each component. This data-driven continuous improvement mechanism ensures that the training system evolves in sync with talent needs.

Future Optimization Pathways

(i) Deepening Dynamic Capability Portrait Driven by AI

Develop a capability evolution model covering the entire undergraduate-graduate period based on the dynamic knowledge graph, integrating multi-source data from curriculum learning, scientific research practice, and project achievements. Using graph neural network algorithms, the system dynamically analyzes the mapping relationship between knowledge nodes and capability indicators. It will automatically track the capability transition trajectory of students from undergraduate basic experiments to graduate innovative projects. For example, by analyzing the correlation weights between "linear algebra knowledge mastery" and "complex system modeling capability", the system generates a visual capability radar chart.

When identifying a capability gap in "machine learning algorithm application", the system will recommend matching complementary courses and scientific research projects, forming a closed-loop evolution path of "data collection - intelligent analysis - precise intervention - effect feedback". This optimization goal will increase the precision of capability cultivation by about 40%, realizing the intelligent leap from "standardized training" to "one-person-one-policy".

(ii) Construction of Virtual Teaching and Research Offices and Interdisciplinary Collaboration

Develop an intelligent matching system for interdisciplinary mentors based on the knowledge graph, , using multi-dimensional labeling to process data on mentors and students according to research directions, technical expertise, and project experience. For example, when an artificial intelligence major student applies to participate in a robot control project, the system will automatically match mentors with backgrounds in machine learning and experience in military projects.

Simultaneously, build a virtual teaching and research platform that supports cross-regional collaboration, integrates AI conference assistance functions (such as real-time semantic analysis, cross-language translation, intelligent agenda generation), and embeds dynamic knowledge graph retrieval modules to enable real-time referencing of cutting-edge technology nodes during discussions. This platform aims to increase the participation rate of interdisciplinary projects from 25% to over 50%, with typical application scenarios including multidisciplinary team collaboration in "intelligent unmanned system" project involving computer science, control engineering, and materials science.

(iii) Integration of Digital Ideological and Political Case Bases

Construct a dynamic knowledge graph integrating ~~an~~ ideological and political education, deeply selecting typical cases in the field of national defense science and technology, such as the "Two Bombs and One

Satellite" spirit and stories of breakthroughs in the manned spaceflight project. Extract ideological and political elements like "patriotism and dedication" and "innovation and breakthrough", and establish associations with professional course knowledge points. For example, embed the domestic endeavors in the development of missile guidance systems within the "Automatic Control Principles" course precisely integrate ideological and political elements. Combine with VR technology to create immersive national defense education scenes, allowing students to virtually experience the whole process of "a team overcoming technological challenges", reinforcing the cultivation of engineering ethics and national sentiment. It is planned to increase the coverage rate of ideological and political cases from 21% to 70% within three years through this system, and establish an ideological and political effect evaluation model based on the knowledge graph, quantitatively analyzing the students' value and ideological manifestations in project reports.

(iv) <u>Flexible Integration and Systematization of AI Ethics</u>

Establish a flexible credit banking mechanism based on the knowledge graph, enabling dynamic recognition and transfer of credits through cross-stage course. For example, the undergraduate course "Signal Detection and Estimation" can be partially credited towards the graduate course "Signal Detection and Estimation Theory" based on weighted calculations. Develop a dynamic exit mechanism that, when a student's training path needs adjustments, recommends the optimal transition plan based on knowledge graph analysis to ensure training continuity. It is planned to incorporate AI ethics courses into the compulsory undergraduate-graduate curriculum system and develop a three-stage module of "basic awareness - technical ethics - strategic application". The undergraduate stage focuses on the use of basic tools like algorithm bias identification, the master's stage delves into ethical decision-making models for autonomous driving, and the doctoral stage emphasizes strategic ethical judgment in AI military applications. Through a virtual simulation case library, cultivate ethical judgment, forming a comprehensive AI ethics education closed-loop to foster talents with both technological innovation and ethical awareness.

Conclusions

This paper proposes a "three-stage goal-oriented" integrated undergraduate-graduate (UG-G) training system based on the dynamic knowledge graph, with the knowledge graph serving as the technological core. The system constructs a three-stage training goal of "strengthen the foundation of basic ability - reinforce professional capability - achieve breakthroughs in innovative capability", achieving seamless connection of undergraduate-graduate stages through the four-dimensional collaboration of curriculum, practice, capability, and management. Pilot programs at Beijing Institute of Technology demonstrate that this system reduces the curriculum repetition rates by 20%, increases students' research participation by 25%, and fosters distinctive training cases such as "intelligent unmanned system".

In the future, further efforts are needed to deepen AI-driven capability portrait and the construction of interdisciplinary virtual teaching and research offices. Within-three years, the plan aims to increase the coverage rate of ideological and political cases from 21% to 70%, promoting the training system to develop towards "dynamic evolution - precise education". At the same time, it is recommended that educational departments issue technical standards, universities establish cross-departmental coordination mechanisms, enterprises co-construct dynamic project pools, to provide innovative paradigm and institutional guarantees for cultivating first-class innovators in national strategic fields.

Acknowledgments

Supported by Special Project Research of Beijing Association of Higher Education (ZX202408).

Bibliographic references

1. Li L. Research on the integration of industrialization and informatization to promote industrial economic transformation and upgrading. Modern Industrial Economy and Informationization. 2023;13(8):97-99.
2. Wang S. Exploring the path of Chinese higher education reform in the context of the new technological revolution. Renming Luntan·Xueshu Qianyan. 2023;(18):14-21.
3. Statistical communiqué of the 2023 national education development. [Accessed 21 May 2025] Available from: http://www.moe.gov.cn/jyb_sjzl/sjzl_fztjgb/202410/t20241024_1159002.html .
4. Shi Y, Yu Y, Liu H., et al. Research on the integrated undergraduate-graduate talent training model towards ability enhancement in the context of new engineering. Journal of Higher Education. 2023;9(11):148-152.
5. Zhang L. Analysis of the pros and cons and countermeasures of the integrated undergraduate, master's, and PhD talent training model. Academic Degrees & Graduate Education. 2015;(6):13-16.
6. Xiong L, Li Z. Exploring the innovative talent training model of undergraduate-master's-PhD integration. Academic Degrees & Graduate Education. 2012; (1):11-15.
7. Ministry of Education, National Development and Reform Commission, Ministry of Finance-Opinions on Accelerating the Reform and Development of Graduate Education in the New Era. [Accessed 2 June 2025] Available from: http://www.moe.gov.cn/srcsite/A22/s7065/202009/t20200921_489271.html.
8. Xing X. Tsinghua's "Qian class": Daring to break barriers—exploring the practice of cultivating first-class innovators in Tsinghua University's Qian Xuesen mechanics class. Educator. 2022; (13):11-13.
9. Huang M, Wang J, Xiao W. Research on the "integrated undergraduate, master's, and PhD" training model in the context of new engineering. Journal of Beijing Institute of Technology (Social Sciences Edition). 2019; 21(06):171-176.
10. Trow M. Problems in the transition from elite to mass higher education. Carnegie Commission on Higher Education; 1974.
11. Engeström Y. Expansive learning at work: toward an activity theoretical reconceptualization. Journal of Education and Work. 2001;14(1):133-156. [Accessed 6 June 2025] Available from: https://psycnet.apa.org/doi/10.1080/13639080123238
12. Lattuca LR, Stark JS. Shaping the college curriculum: academic plans in context. John Wiley & Sons; 2009.
13. Liu Y. Modernization of graduate education governance: background, basic framework, and action strategies. Academic Degrees & Postgraduate Education. 2020; (11):18-24.
14. Jin M, Wang X, Xu G, et al. Exploring the mechanism and model of integrated undergraduate-graduate talent training. Journal of Higher Education. 2023; 10(35): 63-66.

15. Liu J, Xu M. Dilemmas and reconstruction of the integrated PhD training model. Journal of Graduate Education. 2017; (2):47-51.

Conflict of interests:
The authors declare that they have no conflicts of interest.

Authorship contribution:

- He Chen: Project Administration; Funding Acquisition; Resources; Conceptualization; Writing - Review & Editing; Supervision.
- Ling Chen: Methodology; Software; Validation; Formal Analysis; Investigation; Data Curation; Writing - Original Draft; Visualization.
- Mei E: Conceptualization; Methodology; Writing - Review & Editing; Supervision.
- Lu Cheng: Supervision.
- Hongwen He: Supervision.
- Fang Deng: Writing - Review & Editing; Supervision.