Interdisciplinary Research Governance and Sustainable Development Pathways in Universities in Shanghai: A KOEAP Model-Based Empirical Analysis

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Abstract. This study develops and empirically tests the Knowledge-Organization-Environment Analytical Processing (KOEAP) model to explore interdisciplinary governance mechanisms in Shanghai universities. Using panel data from 13 universities, 47 interdisciplinary programs, 34,862 publications, and policy documents from 2015-2024, this study employs AI-enhanced methods including deep clustering, graph neural networks (GNNs), BERTopic, and ensemble learning. Findings reveal: (1) three patterns of interdisciplinary development—advantage-derived, frontier-oriented, and characteristic-cultivating; (2) seven key hub disciplines, with computer science as the top bridge (degree 0.62); (3) organizational collaboration shows the strongest effect (β=0.24, $p<0.01$), moderated by environmental support (β=0.28, $p<0.01$); (4) a four-dimensional sustainability framework. This study contributes to interdisciplinary governance theory and offers practical insights for building sustainable interdisciplinary ecosystems.

Keywords: interdisciplinary research, governance mechanisms, KOEAP model, sustainable development, hub disciplines, social network analysis, AI-empowered empirical analysis, higher education policy

1 Introduction

1.1 Research Background

The increasing complexity of scientific challenges has positioned interdisciplinary research at the forefront of knowledge production. From climate change to public health, pressing problems transcend disciplinary boundaries, necessitating integrated approaches [1]. However, long-term effectiveness depends not only on initial investment but also on governance mechanisms supporting sustainability, including rapid knowledge iteration, high personnel mobility, and policy fluctuations [2].

China has demonstrated strong commitment to promoting interdisciplinary development. The establishment of the Department of Interdisciplinary Sciences within NSFC in 2020, followed by recognition of Interdisciplinary Studies as the 14th

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discipline category in 2021, represents a fundamental restructuring [3]. Shanghai launched the Category IV Peak Discipline initiative in 2016, establishing intra-city collaborative mechanisms [4]. As of 2024, 13 universities in Shanghai have established 47 interdisciplinary programs, providing an ideal context. Universities in Shanghai encounter a unique governance tension. While interdisciplinary programs have expanded rapidly, the evolution of effective coordination mechanisms has lagged behind, potentially resulting in organizational fragmentation and raising questions about the sustainability of these programs over time.

1.2 Theoretical Gap and Research Questions

Existing scholarship has focused on single dimensions—knowledge integration [5], organizational structures, or environmental factors [2]—without systematically examining their interactions. This study addresses two gaps: (1) absence of an integrated framework; (2) insufficient identification of hub disciplines. We propose the KOEAP model and address: What patterns of interdisciplinary development exist? Which disciplines serve as hub disciplines? How do knowledge, organization, and environment influence outcomes? How can a sustainability framework be constructed? These questions are answered in Sections 4.2, 4.3, 4.5, and 5.2 respectively.

1.3 Contributions

This study (1) develops and validates the KOEAP model; (2) identifies seven key hub disciplines; (3) constructs a four-dimensional sustainability framework; (4) demonstrates integration of AI techniques into social science empirical analysis.

2 Literature Review and Theoretical Framework

2.1 Defining Interdisciplinary Research

The National Academy of Sciences defines interdisciplinary research as integrating information, techniques, and theories from two or more disciplines to advance understanding or solve problems beyond a single discipline's scope [6]. Klein distinguishes multidisciplinarity, interdisciplinarity, and transdisciplinarity [5] The evolution of interdisciplinary research has passed through three stages: problem-oriented collaboration (1950-1980), institutionalization (1980-2000), and ecosystem construction (2000-present) [7].

2.2 Hub Disciplines

Hub disciplines have high connectivity in knowledge networks, facilitating cross-disciplinary flows [8]. Prior research identifies mathematics, physics, computer science, and materials science as key hubs [9]. Huang and Xing (2024) found a coreperiphery structure in Chinese universities [10].. Deng et al. (2024) summarized that interdisciplinary program construction is characterized by complex disciplinary spans and dependence on strong parent disciplines [11].

2.3 Organizational and Environmental Dimension

Organizational perspectives focus on structures supporting interdisciplinary collaboration. Mintzberg's structural contingency theory suggests organizational forms must adapt to environmental complexity [12]. From a sustainability perspective, the core of the organizational dimension is structural resilience [13][14]. Environmental perspectives examine contextual factors. Scott's institutional theory identifies regulative, normative, and cultural-cognitive pillars [15]. Core is institutional flexibility [16][17][18].

2.4 The KOEAP Model

Based on the literature, we propose the KOEAP model:

Knowledge Dimension (K): Knowledge regeneration capacity. Hub disciplines play bridging, catalytic, and engine roles.

Organization Dimension (O): Structural resilience. Mechanisms include modular design, matrix management.

Environment Dimension (E): Institutional flexibility. Mechanisms include tiered evaluation, long-cycle assessment.

Analytical Processing (AP): Revealing co-evolution of the three dimensions.

Based on KOEAP, we propose a four-dimensional sustainability framework: structural resilience, institutional flexibility, knowledge regeneration, and co-evolution.

2.5 Research Hypotheses

H1: Knowledge integration is positively associated with interdisciplinary outcomes.

H2: Organizational collaboration is positively associated with outcomes.

H3: Environmental support is positively associated with outcomes.

H4: Organizational collaboration moderates knowledge integration → outcomes.

H5: Environmental support moderates organizational collaboration → outcomes.

H6: Hub discipline network density positively influences outcomes, moderated by organizational collaboration.

Causal logic summary is as follows. K directly enhances outcomes (H1). O directly enhances outcomes (H2) and moderates K→outcome (H4). E directly enhances outcomes (H3) and moderates O→outcome (H5). Hub network density serves as a three-way moderator (H6).

3 Research Methodology

3.1 Research Context

Shanghai provides an ideal context: (1) as China's economic and educational hub, it hosts universities with established interdisciplinary programs; (2) it launched the Category IV Peak Discipline initiative in 2016; (3) comprehensive data availability enables robust analysis.

3.2 Data Sources

This study integrates three data sources. (1) Interdisciplinary program data from the Ministry of Education's official list (47 programs across 13 universities) [19]. (2) Bibliometric data from Web of Science Core Collection (2015-2024), with 34,862 papers classified under two or more categories. (3) Policy documents from the Shanghai Municipal Education Commission and universities (2015-2024).

3.3 Variable Measurement

Dependent Variable: Interdisciplinary publication count (logged).

Independent Variables: Knowledge integration measured by knowledge network density and knowledge heterogeneity. Organizational collaboration measured by cross-institutional collaboration intensity and interdisciplinary program count. Environmental support measured by the Environmental Support Index (ES) constructed through TF-IDF text mining.

Hub Discipline Indicators: Degree centrality, betweenness centrality, and eigenvector centrality.

Control Variables: University type, A-level disciplines count, year fixed effects, university fixed effects.

3.4 Analytical Methods

This study employs a hybrid analytical framework that integrates traditional statistical methods with AI techniques at each stage of empirical analysis. KOEAP conceptual model in Figure 1 illustrates direct effects (H1-H3), moderating effects (H4-H5), and co-evolution feedback loops.

AI-Enhanced Cluster Analysis: Deep clustering using a stacked autoencoder (three hidden layers) followed by K-means on latent representations. This captured non-linear feature interactions. Silhouette score improved from 0.47 (raw K-means) to 0.54; agreement between methods was 92%.

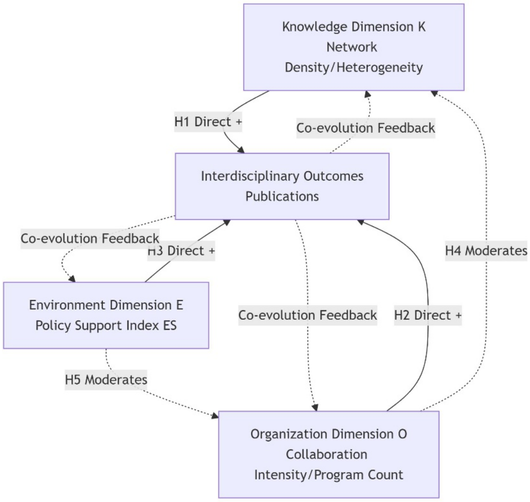

Fig. 1. KOEAP conceptual model

AI-Enhanced Social Network Analysis: GraphSAGE (graph neural network) learned node embeddings (64 dimensions) on the co-authorship network (137 nodes, 1,842 edges). Link prediction accuracy 84% (AUC=0.91). GNN-based modularity optimization improved modularity from 0.31 (Louvain) to 0.35.

AI-Enhanced Text Mining: BERTopic (transformer-based) embedded policy documents using sentence transformers, followed by UMAP and HDBSCAN. Topic coherence (C_v) ranged 0.58-0.72, higher than LDA (0.42-0.55). ES increased from 0.32 (2015) to 0.79 (2024).

AI-Enhanced Panel Data Modeling: Ensemble learning (random forest, XGBoost) as robustness checks. XGBoost achieved OOB R^2=0.68 (vs. fixed effects R^2=0.65). SHAP values revealed non-linear effects (threshold for ES >0.65). Counterfactual simulation: removing Computer Science reduced network connectivity by 34%.

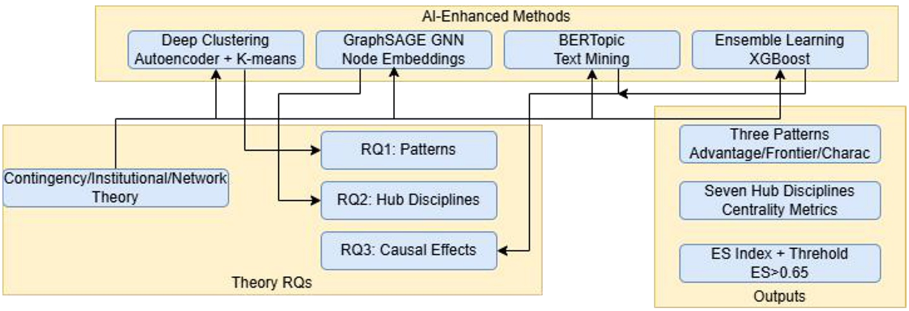

Fig. 2. KOEAP conceptual model

The baseline fixed effects model specification is as in (1).

$$Y_{it} = \alpha + \beta_1 K_{it} + \beta_2 O_{it} + \beta_3 E_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{1}$$

Where Y_{it} is the logged interdisciplinary publication count for university i in year t; K_{it}, O_{it}, and E_{it} represent knowledge, organization, and environment dimensions; X_{it} is a vector of controls; μ_i captures university fixed effects; λ_t captures year fixed effects; and ε_{it} is the error term.

Analytical workflow in Figure 2 shows how AI methods map to theoretical propositions and research questions.

4 Empirical Results

4.1 Descriptive Statistics

Table 1 presents descriptive statistics for 13 universities (2015-2024, 130 observations). Interdisciplinary publications increased from 312 papers in 2015 to 1,247 in 2024.

Table 1. Descriptive Statistics.

Variable	Mean	SD	Min	Max
Interdisciplinary Publications (log)	4.28	1.56	1.79	7.28
Knowledge Network Density	0.198	0.083	0.054	0.342
Knowledge Heterogeneity	0.642	0.114	0.382	0.841
Cross-Institutional Collaboration Intensity	0.316	0.127	0.082	0.578
Interdisciplinary Program Count	3.62	2.41	0.00	9.00
Environmental Support Index	0.53	0.21	0.32	0.79
University Type (research)	0.61	0.46	0	1
A-Level Disciplines	4.31	5.27	0	18

4.2 Cluster Analysis: Three Development Patterns

K-means clustering identified three patterns, validated by deep clustering (92% agreement).

L-Type 1: Advantage-Derived (4 universities). Strong foundation disciplines, moderate span, high program counts. These four 985 universities build programs around strongest disciplines (e.g., vaccinology, low-altitude technology). In the deep clustering latent space, these universities formed a tight cluster (intra-cluster distance 0.32), indicating high internal homogeneity.

Type 2: Frontier-Oriented (5 universities). Strong but not elite disciplines, large span, moderate counts. These universities focus on AI, low-altitude technology, and digital economy.The deep clustering method revealed that two universities in this cluster have high loading on the “AI intensity” latent factor (value >0.8), consistent with their policy emphasis.

Type 3: Characteristic-Cultivating (4 universities). Moderate disciplines, small span, fewer programs. These universities focus on distinctive strengths (e.g., law, language studies). This cluster showed the highest within-group heterogeneity in the deep clustering solution (intra-cluster distance 0.51), reflecting diverse niche strategies.

4.3 Hub Discipline Identification

The disciplinary collaboration network comprised 137 nodes and 1,842 edges (density 0.198). Table 2 shows seven key hub disciplines identified via centrality measures and GraphSAGE.

Table 2. Key Hub Disciplines in universities in Shanghai' Interdisciplinary Collaboration Network.

Type	Discipline	Degree Centrality	Betweenness Centrality	Eigenvector Centrality	Core Function and Role in Sustainability
Cross-Domain Bridging	Computer Science	0.62	0.28	0.91	Connects information, engineering, management. Drives AI+ intersections. Core bridge for knowledge flows.
	Mathematics	0.46	0.19	0.76	Provides formal methods and theoretical foundations. Connects natural and social sciences. Supports knowledge regeneration.
Deep Integration	Clinical Medicine	0.58	0.24	0.86	Integrates biology, pharmacy, engineering. Drives precision medicine. Integration core of biomedical cluster
	Materials Science	0.53	0.21	0.82	Connects physics, chemistry, engineering. Drives new materials R&D. Hub of materials-energy cluster.
	Biology	0.51	0.20	0.79	Connects medicine, environment, agriculture. Knowledge integration center in life sciences.
	Chemistry	0.44	0.16	0.73	Connects materials, environment, pharmacy. Foundational hub in materials science.
Frontier Driving	Environmental Science	0.34	0.10	0.61	Drives sustainability-related intersections. Connects ecology, energy, economy. Knowledge engine for green development

Computer Science had the highest bridge score (0.87). Environmental science showed highest centrality growth (12.3% annually). GNN-based community detection identified four communities: biomedical (0.31), information-intelligence (0.24), materials-energy (0.22), humanities-social sciences (0.12).

4.4 Text Mining: Environmental Support Index

LDA identified six policy themes: discipline layout optimization (0.18), interdisciplinary platform construction (0.16), talent development reform (0.14), evaluation system innovation (0.13), resource allocation priority (0.12), and cross-institutional collaboration (0.11). ES increased from 0.32 in 2015 to 0.79 in 2024 ($r=0.58$, $p<0.01$ with publications).

4.5 Panel Regression Results

Table 3 presents main effects.

Table 3. Panel Data Regression Results for Main Effects.

Variable	Model 1	Model 2	Model 3	Model 4
Knowledge Network Density	0.48*** (0.12)	0.31** (0.11)	0.28** (0.10)	0.26** (0.09)
Knowledge Heterogeneity	0.23* (0.10)	0.19 (0.09)	0.18 (0.09)	0.17 (0.09)
Cross-Institutional Collaboration		0.34*** (0.09)	0.27** (0.08)	0.24** (0.08)
Interdisciplinary Program Count		0.29*** (0.08)	0.21** (0.07)	0.19* (0.08)
Environmental Support Index			0.41*** (0.10)	0.35*** (0.09)
R^2	0.38	0.52	0.61	0.65

*Note: *p<0.05, **p<0.01, **p<0.001

Model 4 shows: knowledge network density (β=0.26, p<0.01), cross-institutional collaboration (β=0.24, p<0.01), and ES (β=0.35, p<0.001) all positively affect outcomes, supporting H1-H3. R^2=0.65 indicates the KOEAP model explains 65% of variance.

Table 4 presents interaction effects.

Table 4. Interaction Effects.

Interaction Term	Coefficient	Standard Error	p-value
Knowledge Network Density × Cross-Institutional Collaboration	0.23	0.09	0.012
Knowledge Network Density × ES	0.11	0.08	0.164
Cross-Institutional Collaboration × ES	0.28	0.10	0.006
Hub Discipline Network Density × Cross-Institutional Collaboration	0.31	0.11	0.004

Significant interactions support H4-H6. Mediation analysis showed cross-institutional collaboration mediated 52.6% of ES's effect on outcomes.

AI-Based Robustness Checks: XGBoost OOB R^2=0.68; top features identical to fixed effects. SHAP revealed threshold effects (ES >0.65). Removing Computer Science reduced connectivity by 34%, confirming backbone role.

5 Sustainable Development Framework

5.1 Connotation and Challenges

Sustainable development of interdisciplinary research refers to the capacity of interdisciplinary ecosystems to continuously operate and evolve. Core connotations include sustained output capacity, environmental adaptability, self-renewal capacity, and co-evolution capacity. Challenges include rapid knowledge iteration, high personnel mobility, lagging evaluation systems, fragmented resource allocation, and policy fluctuations.

5.2 Four-Dimensional Framework

Structural Resilience: Capacity to flexibly adjust while maintaining core functions. Mechanisms: modular organizational design, matrix management, resilient resource allocation, leadership succession.

Institutional Flexibility: Capacity of policy systems to adjust to needs and accommodate innovation. Mechanisms: tiered classification evaluation, long-cycle assessment (5-10 years), dynamic adjustment.

Knowledge Regeneration: Capacity to continuously absorb new knowledge and methods. Mechanisms: hub discipline leadership, knowledge flow platforms, boundary object construction.

Co-evolution: Capacity of knowledge, organization, and environment to mutually reinforce. Mechanisms: knowledge-organization coupling, organization-environment interaction, knowledge-environment feedback.

5.3 Hub Disciplines' Supporting Roles

Hub disciplines play six supporting roles: (1) bridging knowledge flows; (2) catalyzing knowledge integration; (3) driving knowledge innovation; (4) anchoring organizational stability; (5) attracting resource aggregation; (6) serving as sustainability evaluation references.

5.4 Sustainability Pathways

Four pathways are proposed: (1) hub discipline-driven development (advantage-derived universities); (2) frontier breakthrough-driven development (frontier-oriented universities); (3) characteristic-focused development (characteristic-cultivating universities); (4) ecosystem collaborative development (all universities).

6 Discussion and Conclusion

6.1 Theoretical Implications

This study makes four theoretical contributions. First, the KOEAP model provides an integrated framework demonstrating that co-evolution of three dimensions drives sustainable development. Second, seven hub disciplines are systematically identified and categorized into three functional types. Third, a four-dimensional sustainability framework extends research from short-term outcomes to long-term sustainability. Fourth, panel regression results reveal synergistic interactions between knowledge integration and organizational collaboration. Methodologically, AI techniques (deep clustering, GNN, BERTopic, ensemble learning) can be integrated with traditional methods, enhancing robustness.

6.2 Practical Implications

Universities should: (1) identify and cultivate hub disciplines; (2) strengthen organizational collaboration mechanisms; (3) build institutional flexibility through tiered evaluation and long-cycle assessment; (4) construct sustainable ecosystems integrating all four dimensions.

6.3 Limitations and Future Directions

Limitations include: (1) study limited to Shanghai; (2) ten-year window may be insufficient; (3) reliance on quantitative measures. Future research should extend to other regions, incorporate longer periods, and include qualitative studies, and explore causal AI methods.

7 Conclusion

This study developed and empirically tested the KOEAP model, constructing a four-dimensional analytical framework for interdisciplinary ecosystems. Using data from 47 programs across 13 Shanghai universities, it demonstrates that knowledge integration, organizational collaboration, and environmental support interact complexly, with co-evolution as core driver. The seven hub disciplines play critical roles. By integrating AI techniques into empirical analysis, this study shows how computational methods can enhance rigor and interpretability. The KOEAP model and framework offer theoretical tools for understanding interdisciplinary governance and building sustainable ecosystems.

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