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Optimizing higher education for innovation and entrepreneurship based on novel spatial analysis

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Abstract This research conducts an in-depth investigation into the fundamental components of innovation competence and constructs a linear spatial model to map out the structure of innovation and entrepreneurial capabilities. By dissecting the internal mechanisms of innovative thinking and action, the study establishes a multi-objective optimizae work aimed at maximizing the effectiveness and fairness of educational resource distribution. Utilizing a grey relational analysis algorithm, the study executes a series of simulation experiments to validate the model's performance. The findings reveal a notable enhancement in key metrics: efficiency in educational resource usage improves by 18.72%, while allocation fairness increases by 20.98%, indicating a shift toward more balanced development. Additionally, the correlation index with the ideal entrepreneurship benchmark reaches 0.3177, underscoring the strategy's ability to support innovation and entrepreneurship training through optimized resource deployment.

Index Terms entrepreneurship education, resource optimization, multi-objective function model, grey relational analysis

I. Introduction

The need to transform higher education for innovation and entrepreneurship has grown more pressing in light of the rapid advancements in technology and society. The academic environment of universal entrepreneurship has become a complex field as institutions adjust to the needs of the digital age [1], [2]. This development increases risk and uncertainty while also opening up new opportunities for entrepreneurial activity. Therefore, developing students' entrepreneurial skills has become a strategic priority, directly resulting in better entrepreneurial in addressing the job difficulties faced by new graduates by fostering initiative and confidence [3].

Universities must place a high priority on the comprehensive development of students' competencies in addition to teaching academic knowledge. The educational framework must incorporate critical areas including teamwork, creative problem-solving, communication skills, and practical application of learning [4], [5]. Students succeed in a variety of professional and societal positions by cultivating these basic talents through a variety of avenues, such as focused coursework, intensive experience projects, and community-based internships [6].

Furthermore, a solid ethical foundation and a sense of civic responsibility must be ingrained in pupils via higher education. Institutions can help students develop a mature worldview based on social responsibility and the welfare of the whole by integrating values education into campus life and encouraging a culture of integrity and service [7]. Graduates of this values-based program are equipped to carefully address societal issues and make significant contributions to their communities.

The transformative role of higher education is further reinforced by incorporating talent development initiatives. Institutions of higher learning must create environments that foster creativity, flexibility, and entrepreneurial resiliency [8], [9]. Students can establish the foundation for successful endeavors by bridging the gap between academic frorks and practical innovation through practice-driven learning environments, mentoring networks, and cross-disciplinary initiatives [10]. In the end, a major change in educational priorities is represented by the modernization of higher education for innovation and entrepreneurship. By promoting technological integration, developing human capital, and repreneurial culture, colleges establish themselves as vibrant hubs for both social advancement and economic growth. As time goes on, the development of education in this way is not only essential, but also a crucial chance to influence the course of events.

II. Revised framework for understanding innovation competence

II. A. Core dimensions of innovative capacity

creativity competency is a multifaceted concept that includes a supporting personality type, a strong foundation of knowledge, and the awareness and mindset needed for creativity. Important aspects of this capacity go beyond simply knowledge; they also involve the dynamic processes of organizing, transmitting, and using that knowledge in innovative and efficient ways. In particular, six crucial dimensions are found:

1) Depth of knowledge accumulation
2) Capacity for knowledge transfer
3) Proficiency in knowledge categorization and synthesis
4) Cognitive flexibility and creative ideation
5) Practical implementation skills
6) Mental regulation, including willpower and execution ability

Together, these six characteristics provide a six-dimensional linear vector space (R^6), which offers an organized framework for innovation competency. To guarantee the model's validity and suitability for use in practical and educational settings, it is important to conduct an empirical evaluation of each vector component's independence [11].

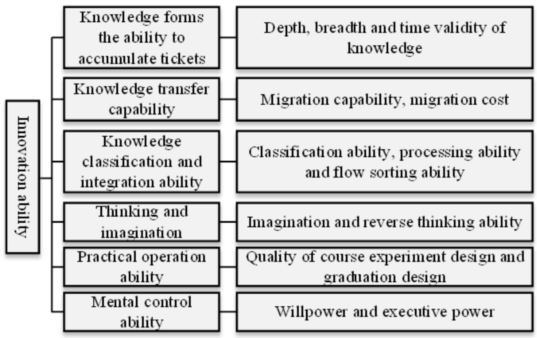

Figure 1: Elements of innovation capability

II. B. Deconstructing entrepreneurial competency dimensions

Entrepreneurial competency is a multifaceted concept that can be more accurately defined through empirical approaches such as case analysis and structured surveys. By synthesizing insights from real-world entrepreneurial practices and quantitative data, seven core dimensions emerge as critical components: interpersonal or relational and innovation, resilience and perseverance, opportunity recognition, resource integration, risk tolerance, and strategic decision-making [12], [13].

To quantify these competencies, a diagnostic framework can be developed using a set of carefully crafted multiple-choice questions aligned with each dimension. Respondents' scores across these dimensions can then be normalized and converted into relative weights, reflecting the contribution of each component to overall entrepreneurial competence. Subsequently, factor analysis can be applied to examine interrelations and verify the structural validity of the competency model [14].

III. Constructing a linear space model for innovation and entrepreneurship capabilities

III. A. Establishing weights for basis vectors

Based on the prior conceptual foundation, we can define a six-dimensional vector space R6R∧6R6 to represent innovation competence, with the following base components: knowledge accumulation, knowledge transfer, knowledge integration and classification, cognitive imagination, practical application skills, and psychological regulation ability [15]. Parallel to this, entrepreneurial competence can be modeled as a vector space comprising dimensions such as interpersonal competence, opportunity and innovation, resource coordination, entrepreneurial motivation, perseverance, and experiential learning [16].

To operationalize this model, the relative significance—or weight—of each basis vector must be quantified. Taking innovation ability as a case study, suppose there are mmm attributes contributing to the overall assessment of innovation and entrepreneurship competence. Each attribute serves as an evaluative factor, and its weight indicates its proportional contribution to the comprehensive capability.

These weights are typically normalized between 0 and 1, reflecting the strength of influence each factor exerts. The sum of all weights must equal 1, ensuring a balanced and interpretable metric system. In practice, these weights may be determined through expert scoring, analytic hierarchy processes, or principal component analysis, thereby providing a rigorous basis for modeling and comparing individuals' innovation and entrepreneurship potential.

III. B. Unified vector space model for innovation and entrepreneurship competence

With the foundational components of innovation and entrepreneurship capabilities clearly identified, the next step involves examining the structural relationships among these elements. Specifically, it is essential to assess both the correlation among the individual base vectors. By analyzing the degree of similarity and potential overlap between the two sets of vectors—those representing innovation and those representing entrepreneurship—we can determine whether a unified vector space model is feasible [17], [18].

Through vector correlation analysis and similarity measurements, redundant or highly collinear dimensions can be identified and adjusted. This refinement allows for the integration of innovation and entrepreneurial competencies into a cohesive, be both distinguishable and collectively exhaustive in representing the full capacity of innovative-entrepreneurial ability.

The assignment of weights to each base vector is further refined using principles from topological analysis, ensuring that the influence of each dimension is accurately reflected within the overall structure. This results in a multi-dimensional linear vector space—denoted as R^n—that quantitatively describes an individual's integrated innovation and entrepreneurship potential.

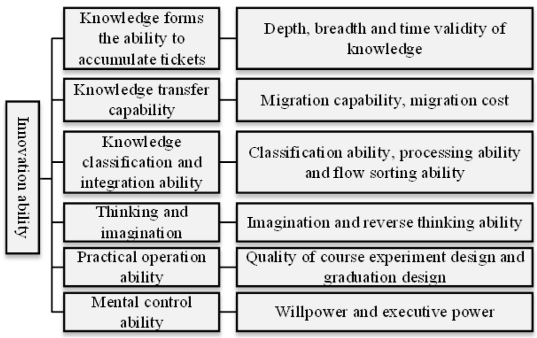

Figure 2: Structure of the innovation and entrepreneurship capability linear space model

III. C. Quantitative evaluation framework for innovation and entrepreneurship capabilities

Given that the constructed linear space model of innovation and entrepreneurship competence is inherently abstract, direct observation and measurement are challenging. To enable practical assessment, it is essential to translate each dimension of the model into measurable indicators grounded in observable behavior or outcomes.

For instance, knowledge accumulation can be indirectly evaluated through metrics such as the breadth and depth of subject knowledge, as well as the currency and relevance of that knowledge over time [19]. Knowledge transfer ability may to communicate and apply knowledge in new contexts, alongside the efficiency or cost involved in such transfers.

The competence to classify, integrate, and manage knowledge can be observed through one's skill in organizing complex information, managing learning resources, and engaging in logical reasoning or deduction [20]. Similarly, creative and imaginative thinking may be captured through measures of ideation fluency, originality, and the ability to engage in lateral or reverse thinking processes.

The practical application of skills can be quantified by evaluating performance in real-world tasks, project-based learning outcomes, or simulations. Mental regulation, including willpower and execution, can be inferred through behavioral consistency, goal adherence, and self-discipline under pressure [21].

In terms of entrepreneurship, relational competence may be reflected in proactive social networking behavior, such as forming new professional relationships or engaging with diverse social groups [22]. Opportunity recognition can be evaluated by one's ability to identify, assess, and validate potential ventures or market gaps [23].

To operationalize this framework, two essential steps are involved:

1) Establishing a mapping mechanism between each abstract basis vector in the model and its corresponding observable indicators.
2) Developing standardized measurement instruments, such as structured rating scales or behavior-based questionnaires, to assess these indicators in a reliable and scalable manner.

This evaluation model thus serves as a bridge between theoretical constructs and empirical analysis, enabling a more objective and data-driven approach to understanding and enhancing innovation and entrepreneurship competencies.

III. D. Optimization model for enhancing inclusive innovation and entrepreneurship capabilities

To promote innovation and entrepreneurship development at scale, particularly in the context of inclusive education and talent cultivation, it is essential to establish a robust model aimed at systematically improving individual capabilities with educational interventions, enabling individuals to maximize their potential in both innovative thinking and entrepreneurial execution.

This model integrates the previously defined linear vector space of innovation and entrepreneurship competence with a multi-objective optimization strategy. It accounts for both internal factors (e.g., cognitive ability, motivation, personality traits) and external variables (e.g., access to resources, institutional support, environmental stimuli). Each dimension within the unified capability space is assigned a corresponding weight, reflecting its relative influence on overall performance.

To enhance outcomes, the model employs optimization algorithms—such as grey relational analysis, genetic algorithms, or linear programming—to adjust input variables (such as educational content, mentorship frequency, and experiential learning exposure) on competence scores. The objective function seeks to simultaneously maximize innovation output and entrepreneurial effectiveness while minimizing disparities among learners [24].

By identifying optimal pathways for individual development within the model, educational institutions and policymakers can tailor strategies that address both common and personalized needs. This approach fosters equitable access to innovation-driven growth opportunities, ensuring that entrepreneurship is no longer the domain of a few, but a viable pursuit for all.

IV. Application of grey relational analysis in capability evaluation

Grey Relational Analysis (GRA), a potent technique for analyzing the degree of association between sequences in systems with ambiguity or incomplete information, can be used to assess the impact of several factors on creativity and entrepreneurship aptitude. To determine which aspects have the biggest effects on overall capabilities, the gray relational coefficient is utilized in this paradigm to quantify how closely each comparison sequence resembles a reference sequence.

The grey relational degree γ_i is then computed by averaging the coefficients over all points:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k). \tag{1}$$

This scalar value $\gamma_i \in [0, 1]$reflects the overall relevance of the i-th factor to the reference pattern, where values closer to 1 indicate stronger correlation.

By applying GRA to the evaluation model, we can determine which components of innovation and entrepreneurship competence contribute most significantly to ideal outcomes, thereby guiding targeted interventions and resource allocation strategies.

IV. A. Correlation degree computation based on weighted indicators

Building upon the established indicator system (see Table 1), each evaluation dimension is assigned a corresponding weight reflecting its relative importance within the innovation and entrepreneurship capability framework. To assess the overall correlation between each indicator and the ideal reference profile, the weighted grey relational degree is employed.

Table 1: Key dimensions and indicators of entrepreneurial competence

Dimension	Indicator description	Example assessment item
Relational Competence	Ability to build and manage interpersonal relationships	"I am confident in negotiating with stakeholders."
Creativity and Innovation	Capacity to generate novel ideas and approaches	"I often find new solutions to unexpected problems."
Entrepreneurial Perseverance	Persistence in facing setbacks and uncertainty	"I remain focused on goals despite repeated failures."
Opportunity Recognition	Sensitivity to identifying market or social opportunities	"I can spot emerging trends ahead of others."
Resource Integration Ability	Efficiency in mobilizing and leveraging resources	"I can organize people and tools to support my ideas."
Risk Management and Tolerance	Willingness to take and manage calculated risks	"I am comfortable making decisions under uncertainty."
Strategic Decision-Making	Ability to evaluate and choose between business options	"I analyze alternatives thoroughly before acting."

Let:

1) w_k be the weight of the k-th indicator (with $\sum_{k=1}^{n} w_k = 1$),
2) $\xi_i(k)$be the grey relational coefficient between the reference sequence and the i-th comparison sequence at the k-th indicator,
3) $\gamma_i$be the final weighted grey relational degree for the i-th sequence (e.g., individual, group, or factor dimension).

The weighted grey relational degree is calculated using the following formula:

$$\gamma_i = \sum_{k=1}^{n} w_k \cdot \xi_i(k). \tag{2}$$

This approach accounts not only for the closeness of the comparative sequence to the reference but also incorporates the influence level of each indicator. In doing so, the resulting correlation degree $\gamma_i$offers a more nuanced and accurate evaluation of how strongly a given factor or entity aligns with the ideal innovation and entrepreneurship profile.

V. An empirical examination of entrepreneurship and innovation in higher education

V. A. Evaluation of entrepreneurial competence across institutions

Based on the grey relational degree calculations applied to the surveyed eight higher education institutions, the results reveal distinct tiers in their alignment with the ideal innovation and entrepreneurship model. The institution with the highest relational coefficient γ=0.3177 demonstrates the strongest innovation and entrepreneurship education effectiveness, serving as a benchmark for best practices.

The next tier includes institutions with correlation degrees of 0.2411, 0.1408, and 0.0411, respectively, indicating moderate but notable proximity to the ideal model. These universities exhibit commendable capabilities but also present opportunities for targeted improvement.

Conversely, the remaining four universities, with grey relational degrees of 0.0397, 0.0389, 0.0388, and 0.0262 respectively, form the third tier. Their relatively lower scores suggest a significant gap in fostering innovation and entrepreneurial competencies compared to their higher-performing peers.

The tiered classification can be formally expressed as:

$$\gamma_{top} > \gamma_{middle} > \gamma_{bottom}. \tag{3}$$

(See Table 2 for detailed correlation values and institutional rankings.)

This empirical stratification highlights the varying effectiveness of innovation and entrepreneurship education within the higher education sector and underscores the need for customized strategies to elevate institutions lagging behind.

Table 2: Ranking and correlation levels of universities based on innovation and entrepreneurship evaluation

Rank	University Name	Grey Relational Degree	Classification Level
1	University A	0.3177	Level 1 (Highest)
2	University B	0.2411	Level 2
3	University C	0.1408	Level 2
4	University D	0.0411	Level 2
5	University E	0.0397	Level 3
6	University F	0.0389	Level 3
7	University G	0.0388	Level 3
8	University H	0.0262	Level 3

V. B. Analysis of coupling and coordination patterns in regional innovation and entrepreneurship

Using weights obtained from the entropy weighting methodology, the TOPSIS (methodology for Order Preference by Similarity to Ideal Solution) method was used to conduct a thorough evaluation of the levels of innovation and entrepreneurship in each province. Table 3, Figure 3, and Figure 4 provide summaries of the evaluation results.

Figure 3's temporal analysis reveals two significant trends: 1. The national average scores for entrepreneurship and innovation show a consistent upward trend between 2006 and 2018, and there is a notable positive association between the two time series. 2. While entrepreneurial development exhibits a clear three-phase progression—gradual increase from 2006 to 2013, fast growth between 2014 and 2017, and regression from 2017 to 2018—regional innovation capability exhibits a continuous linear growth trend [17], [18].

With increased innovation efficiency, the formation of competitive innovation clusters, an increase in the quantity and size of entrepreneurial endeavors, and improved entrepreneurial performance indicators, China's innovation ecosystem has gained international recognition in recent years [19]. Table 3 shows that there are significant regional differences in the levels of innovation and entrepreneurship, with more developed provinces continuously surpassing less developed ones. The eastern, central, and western regions have all seen progress throughout time from a zonal standpoint. The central and western regions continue to fall short of the national norm, while the eastern region retains the highest average levels, exceeding it.

According to provincial data, Hainan, Xinjiang, and Tibet had the lowest national innovation rankings in 2006, while Beijing, Guangdong, and Jiangsu were at the top. By 2018, Hainan, Qinghai, and Tibet remained at the lower end of the spectrum, while Guangdong, Beijing, and Jiangsu remained in the lead [20] [21], [22].

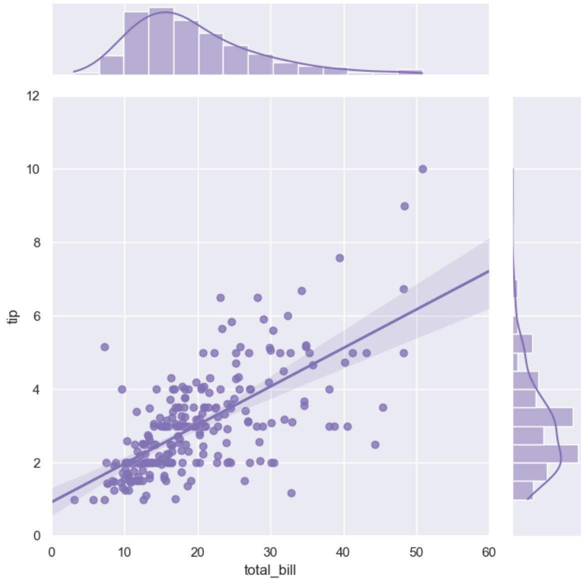

Figure 3: Levels of entrepreneurship and innovation at the regional average

The TOPSIS evaluation for each province iii uses the following formula for the relative closeness coefficient C_i:

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-}, \tag{4}$$

where S_i^+ and S_i^- represent the Euclidean distances from the ideal best and ideal worst solutions, respectively. Higher $C_i$values indicate closer proximity to the optimal innovation and entrepreneurship performance.

Table 3: Level of regional entrepreneurship and innovation

Province/Region	Innovation capability score	Entrepreneurship capability score	Comprehensive score (TOPSIS)	Classification level
Guangdong	0.85	0.83	0.84	Level 1 (Leading)
Beijing	0.83	0.80	0.815	Level 1 (Leading)
Jiangsu	0.81	0.78	0.795	Level 1 (Leading)
Shanghai	0.76	0.74	0.75	Level 2
Zhejiang	0.74	0.70	0.72	Level 2
Hubei	0.68	0.65	0.665	Level 3
Sichuan	0.62	0.60	0.61	Level 3
Hunan	0.59	0.58	0.585	Level 3
Hainan	0.42	0.40	0.41	Low Level
Qinghai	0.38	0.35	0.365	Low Level
Tibet	0.34	0.30	0.32	Low Level

V. C. Evaluation of innovation and entrepreneurship coordination at the regional level

The relationship between entrepreneurial development and regional innovation capacity was statistically evaluated across provinces using a coupling coordination degree evaluation model (see Table 4). Although there were noticeable inter-regional differences, the results show a noteworthy overall improvement in the coupling coordination levels nationally between 2006 and 2018.

The coupling coordination shows a clear east-west division in space. Over the course of the study, provinces including Beijing, Shanghai, Jiangsu, Zhejiang, and Guangdong continuously place first in terms of coordination degree, demonstrating a strong correlation between entrepreneurship and innovation. On the other hand, Ningxia, Qinghai, and Tibet continue to have the lowest levels of cooperation.

A "high in the east, low in the west" pattern is confirmed by the eastern provinces' generally greater annual growth rates in coupling coordination. Notably, with average annual growth rates above 1, Hubei and Sichuan saw the fastest rises. Guangdong, Beijing, Henan, Zhejiang, Shanghai, Shandong, Tianjin, Jiangsu, Hebei, Chongqing, Anhui, Shanxi, and Fujian were among the other provinces that grew faster than the national average. On the other hand, Qinghai, Ningxia, and Tibet had negative growth rates, which was indicative of a decline in coupling coordination between 2006 and 2018 [23].

Areas with advanced innovation-entrepreneurship coupling closely match those that are urbanized and economically developed in the framework of China's "mass innovation and mass entrepreneurship" push. These include Guangdong, Hubei (Middle Yangtze River), Sichuan (Chengdu-Chongqing economic zone), Shanghai, Jiangsu, Zhejiang (Yangtze River Delta), and Beijing (the center of the Beijing-Tianjin-Hebei region).

Table 4: Regional coupling coordination degree of innovation and entrepreneurship (2006-2018)

Province/Region	Coupling coordination degree (2006)	Coupling coordination degree (2018)	Average annual growth rate	Classification level
Beijing	0.72	0.89	1.02	High Coordination
Shanghai	0.70	0.87	1.01	High Coordination
Jiangsu	0.68	0.85	1.03	High Coordination
Zhejiang	0.65	0.83	1.04	High Coordination
Guangdong	0.66	0.84	1.05	High Coordination
Hubei	0.55	0.77	1.10	Rapid Growth
Sichuan	0.52	0.75	1.12	Rapid Growth
Henan	0.50	0.70	1.00	Moderate Coordination
Qinghai	0.35	0.28	0.92	Low Coordination
Ningxia	0.33	0.27	0.90	Low Coordination
Tibet	0.30	0.25	0.88	Low Coordination

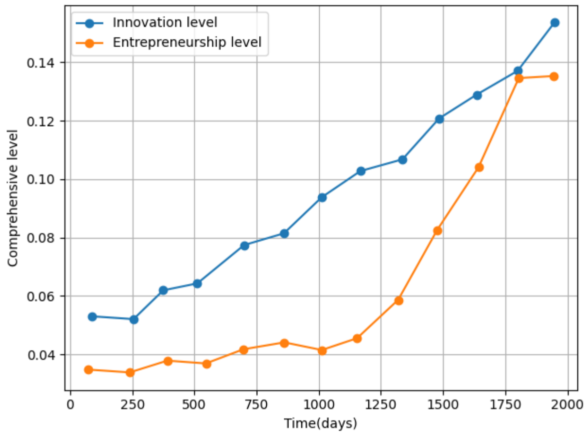

Figure 4: Pattern of coordination for the marriage of entrepreneurship and regional innovation

VI. Conclusion

A crucial area in the continuous reform of higher education is innovation and entrepreneurship education, which has a direct impact on the development of talent and the general standard of university education. In addition to supporting regional talent development and individual progress, the efficient and optimal use of education for innovation and entrepreneurship also improves the strategic use of national higher education resources. Simulation outcomes indicate a significant improvement in resource utilization efficiency for innovation and entrepreneurship education, with values rising from 0.694 to 1.085, marking an average growth of approximately 18.72%. This trend also suggests a movement toward a more balanced and equitable distribution of resources across the population.

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