Construction and Research of the Core Competency System for Outstanding Innovative Talents Based on the Grey Fuzzy Comprehensive Evaluation Method

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Abstract: *The new round of scientific and technological revolution and industrial transformation is developing rapidly. Higher education urgently needs to cultivate a large number of outstanding innovative talents. Exploring the core competencies of outstanding innovative talents has important theoretical and practical significance. In this study, through literature review, expert interviews, and questionnaire surveys, the key influencing factors of the core competency system for outstanding innovative talents were first determined. Then, the factor analysis method was used to establish the evaluation index system for the core competencies of outstanding innovative talents, and the grey fuzzy comprehensive evaluation method was adopted to construct the evaluation model for the core competencies of outstanding innovative talents. Finally, a certain university was selected as the evaluation object, an expert evaluation matrix was established, and the evaluation results of the core competencies of outstanding innovative talents in this university were obtained. The results show that the core competency system for outstanding innovative talents constructed in this study is scientific, reasonable, and of high quality, with the expectation of providing theoretical guidance and practical paths for the cultivation of outstanding innovative talents in higher education.*

Keywords: *Outstanding innovative talents; Factor analysis method; Grey fuzzy comprehensive evaluation method; Core competencies*

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1. Introduction

At present, the new round of scientific and technological revolution and industrial transformation is restructuring the global innovation landscape and reshaping the global economic structure, driving fundamental changes in human lifestyle, production mode, and way of thinking. Outstanding innovative talents have gradually become the decisive factor in a country's economic strength and global competitiveness. The fundamental vitality of universities in society lies in innovation. To develop new productive forces, it is urgent to cultivate and bring up a large number of outstanding innovative talents. Core competencies are the key abilities and essential qualities that outstanding innovative talents possess. They comprehensively reflect multiple aspects such as knowledge, abilities, emotions, and attitudes[1]. They are the key elements for improving the cultivation ability and quality of outstanding innovative talents, and have far-reaching value for outstanding innovative talents to serve the construction of a powerful higher education country, promote independent innovation in science and technology, and adapt to the high-quality development of the economic society.

2. Research Status

The core competencies in American universities focus on cultivating students' independent thinking and the abilities to discover and solve problems. They are implemented through the combination of in-class and out-of-class activities, the integration of science and humanities, and the combination of teaching and research. The talent cultivation in German universities adopts the "dual" model of schools and enterprises[2]. The core competencies pay attention to students' creative thinking, actions in line with moral principles, practical abilities, and future learning abilities. The core competencies in British universities integrate long-standing traditions with modern educational concepts. By combining academic freedom with structured support[3], they focus on cultivating students' global vision, in-depth professional abilities, and cross-border innovative thinking.

Chinese universities focus on deepening reforms in the cultivation of outstanding innovative talents and actively explore and practice. Tsinghua University pays attention to students' cross-border abilities, scientific research abilities, practical abilities, and innovative abilities. It implements the cultivation plan for outstanding innovative talents by gathering first-class scholars at home and abroad, building cutting-edge interdisciplinary platforms, carrying out high-level scientific research, and conducting diverse academic exchanges[4]. Peking University attaches importance to students' general education, learning freedom, professional abilities, and autonomous learning abilities. Through innovative cultivation models, creating first-class teaching staff, strengthening original innovation, and deepening cooperation and exchanges, it accelerates the cultivation of outstanding innovative talents in basic disciplines. Zhejiang University focuses on students' general education, autonomous learning abilities, personalized learning methods, and global vision. It has established a curriculum system of "emphasizing the foundation, having a broad caliber, and being modular"[5], built an innovation-oriented international exchange platform, and created a competitive and cooperative growth environment for students. Harbin Institute of Technology cultivates students' discovery ability, imagination, insight, and creativity, and accelerates the implementation of the talent cultivation system of "mathematical and physical foundation + field foundation + interdisciplinary integration" and

"1+1+X"[6].

3.Construction of the Evaluation Index System for the Core Competencies of Outstanding Innovative Talents

3.1 Principles for Constructing the Index System

(1) Comprehensiveness principle.

The evaluation index system should comprehensively cover various characteristic indicators of the evaluation object, grasp the overall situation, and cover all aspects related to the evaluation objective to achieve an accurate assessment of the overall situation of the evaluation object.

(2) Hierarchical principle.

The indicators at all levels of the evaluation index system should show a progressive relationship. The lower-level indicators should support and serve the higher-level indicators, forming a hierarchical structure to provide a solid foundation for further index analysis and thus provide strong support for more specific data analysis and decision-making.

(3) Purposefulness principle.

The indicators at all levels of the evaluation index system should serve the overall evaluation objective. The lower-level indicators should be developed around the upper-level indicators, interlocking with each other to ensure that the final evaluation results meet the initial evaluation objective.

3.2 Construction of the Evaluation Index System

3.2.1 Identification of Influencing Factors

In this study, first, keywords such as "outstanding innovative talents", "core competencies", "scientific and technological innovation", and "integration of industry and education" were used to conduct literature searches on platforms such as CNKI, Wanfang Data, and Web of Science at home and abroad. The different perspectives and opinions on the core competencies of outstanding innovative talents were collected and analyzed, and the initial set of influencing factors for the core competencies of outstanding innovative talents was sorted out. Then, the Delphi method was adopted. Professionals and scholars in the fields of higher education, scientific and technological innovation, and industry were invited to form an expert group. An initial questionnaire was designed. After three rounds of opinion collection and improvement, in the third round of opinion collection, no experts put forward opinions on the initial set of influencing factors, and the expert group basically reached a consensus. Finally, the key influencing factors set for the core competencies of outstanding innovative talents are shown in Table 1.

Table 1.Key Influencing Factors Set of Core Competencies of Outstanding Innovative Talents

Number	Impact factor	Description	Source
F1	Interdisciplinary knowledge	The integration of knowledge across disciplines promotes comprehensive problem solving skills.	Zhong B L and Li C Z et al[7]

F2	Professional competence	High level of technical ability and the ability to adapt to the development of new technologies.	Barak, M and Yuan, S [8]
F3	Innovation ability	Creative thinking and innovation ability to develop new ideas and solutions.	Shi Q H and Li R[9]
F4	Critical thinking	The ability to critically analyze and think independently.	Zheng C.Y.and Hu H.K et al [10]
F5	Practical Skills	Practical skills acquired through internships, projects and practical problem solving.	Winks L et al [11]
F6	Ethical awareness	Understanding and commitment to ethical standards and social responsibility.	Lu, X. R [12]
F7	Global vision	Knowledge of global trends and the ability to operate in a global context.	Wang H C and Liu S Q[13]
F8	Team collaboration ability	The ability to work effectively in a team and collaborate with others.	Yu J X et al [14]
F9	Leadership	The ability to lead and motivate others in a variety of situations.	Yu N N et al [15]
F10	University-Enterprise cooperation	Cooperation between universities and enterprises in personnel training, scientific research and technological transformation.	Wang Y P et al[16]
F11	Communication	Proficiency in oral and written communication.	Xiang C [17]
F12	Adaptability	The ability to adapt to changing circumstances and challenges.	Li M Z and Sun Y Z[18]
F13	Professional knowledge	Theoretical knowledge in one's own major field of study.	Bao S M and Chen Q P[19]
F14	Engineering knowledge	Knowledge involved in participating in engineering projects.	Laurett R,and Paço A et al[20]
F15	Humanistic knowledge	The acquisition of knowledge about human history, culture, etc.	Wu, J. N. and Hua, Z. Y [21]

3.2.2 Exploratory Factor Analysis

Exploratory Factor Analysis (EFA) is a commonly used data dimensionality reduction technique that can identify the latent factor structure and explore the relationships between variables, helping to identify the relationships between strategies. When constructing the evaluation index system of the core competencies of outstanding innovative talents, the primary step is to conduct exploratory factor analysis on all the indicators to achieve the stratification of the evaluation indicators. In this study, the EFA technique is applied through SPSS 24 software to analyze the construction of the evaluation index system of the core competencies of outstanding innovative talents. First, the extraction method of principal component analysis is

adopted to determine the contribution rate of latent factors, and the varimax rotation method is used to rotate the factors. After determining the factor structure, the extracted factor classes are interpreted and named to clarify the stratification results of different indicators. Then, the stratification and weight data of the evaluation index system are obtained. A questionnaire is designed based on the evaluation index set for outstanding innovative talents, and data on the relative importance of the evaluation indicators are collected through the questionnaire survey. The questionnaire design adopts a five-level Likert scale, ranging from 1 = strongly disagree to 5 = strongly agree. The questionnaire consists of three parts: The first part introduces the detailed situation, objectives, and contact information of the research; the second part collects 5 items of personal information of the research objects; and the final part introduces 22 strategies determined from the literature review and expert opinions.

The objects of the questionnaire survey are different stakeholders in the cultivation of outstanding innovative talents in universities, and the respondents are required to rate the importance of the evaluation indicators. In this study, a total of 68 people were interviewed. The detailed information of the respondents shows that 24 (35%) of the respondents are university students, 17 (25%) of the respondents are university teachers, 16 (24%) of the respondents are scientific researchers in relevant fields, and 11 (16%) of the respondents are university administrative staff. The sample size is scientific, reasonable, and representative. A limitation of this study is that the EFA sample (n=68) did not include industry stakeholders, and future research is recommended to incorporate such stakeholders to enhance the generalizability of the findings.

The Kaiser-Meyer-Olkin (KMO) test and Bartlett's spherical test are applied to determine whether the data are suitable for EFA. The calculation results show that the KMO value is 0.637, reaching the minimum critical value level of 0.5, and the significance level of Bartlett's test is 0.000, also meeting the requirements, indicating the data applicability for factor analysis and extraction of the factor structure, and showing that the sample is sufficient for the EFA test results. The results show that all factor loadings are higher than the minimum standard of 0.50, and all variables (indicators) can be retained. Further, factors with eigenvalues greater than 1 are extracted, and four factors are obtained to establish the basic factor structure of the evaluation indicators of the core competencies of outstanding innovative talents, as shown in Table 2.

Table 2.Factor Analysis Results of the Evaluation Indicators of the Core Competencies of Outstanding Innovative Talents

Number	Secondary index	Common factor 1	common factor 2	common factor 3	common factor 4
F1	Interdisciplinary knowledge	0.704			
F2	Professional ability	0.728			
F3	Innovation ability	0.831			
F4	Critical Thinking	0.827			
F7	Global Vision	0.762			
F5	Practical ability		0.738		

F6	Ethical consciousness	0.744			
F10	School-enterprise cooperation	0.89			
F12	Adaptability	0.888			
F8	Team collaboration ability		0.809		
F9	Leadership ability		0.707		
F11	Communication ability		0.908		
F13	Professional knowledge				0.821
F14	Engineering knowledge				0.769
F15	Humanistic knowledge				0.829

Factor loading represents the correlation between variables and factors. The greater the loading, the closer the relationship between the variable and the factor, and the greater the contribution of the variable to the factor, and thus the greater the weight that should be assigned. According to the indicators with high factor loadings and similar meanings for each factor, all indicators are divided into four-dimensional indicators, which are named comprehensive ability, social ability, communication and collaboration ability, and lifelong learning ability. These dimensions can be regarded as the first-level indicators of the evaluation index system of the core competencies of outstanding innovative talents. Therefore, based on the results of factor analysis, the constructed two-layer evaluation index system of the core competencies of outstanding innovative talents is shown in Figure 1.

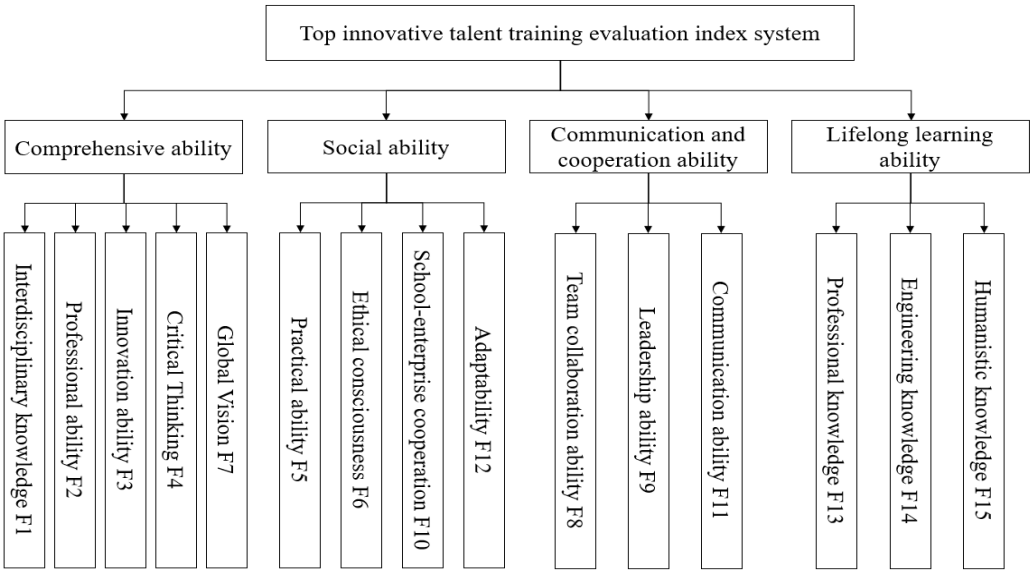

Figure 1.Evaluation Index System of the Core Competencies of Outstanding Innovative Talents

3.3 Establishment of Evaluation Index Weights

This paper conducts factor analysis on 68 pieces of questionnaire data, summarizes four first-level indicators, and determines the load of each indicator in these common factors. The calculation formula for the index weight uses the factor loading and variance contribution results of factor analysis, and the formula is as follows:

$W_i = \sum_{j-1}^{n}(load_{ij} * \text{Variance contribution rate}_j)$, where n is the total number of common factors, that is, n = 4. After calculating the index weight, normalization processing is required, and the calculation formula is $W_{i'} = \frac{W_i}{\sum_{i=1}^{15} W_i}$. The unnormalized weight formula integrates multi-dimensional expert weights and indicator-factor loadings, preserving the differentiated contributions of expert experience while enhancing the correlation strength between indicators and target factors, thus comprehensively reflecting the practical importance of each indicator in comprehensive evaluation[20]. The calculation results of the index weight and the normalized weight are shown in Table 3.

Table 3.Weights of the Evaluation Index System for Top-Notch Innovative Talent Training

Number	Level-1 indicator	Level-2 indicator	Unnormalized Weight	Normalized weight
F1	Integrated competence	Interdisciplinary knowledge	0.079646	0.0411
F2		Professional ability	0.106825	0.0551
F3		Innovation ability	0.180471	0.0931
F4		Critical Thinking	0.149372	0.0771
F7		Global Vision	0.187517	0.0968
F5	Social Competence	Practical competence	0.107873	0.0557
F6		Ethical Awareness	0.140267	0.0724
F10		School-Enterprise cooperation	0.131825	0.068
F12	Communication and collaboration ability	Adaptability	0.113928	0.0588
F8		Team collaboration ability	0.131992	0.0681
F9		Leadership	0.172297	0.0889
F11		Communication ability	0.142627	0.0736
F13	Education Resources	Professional knowledge	0.175428	0.0905
F14		Engineering knowledge	0.152255	0.0786
F15		Humanistic knowledge	0.143643	0.0741

It can be seen from the above table that the weight distribution of each indicator in the evaluation system is relatively balanced, but it also reflects the differences in the importance of each indicator. Among them, the factors of comprehensive ability, social ability, communication and collaboration ability, and lifelong learning ability have relatively high loadings in their respective factors, highlighting their key role in the core competency system of outstanding innovative talents. This evaluation index system lays the foundation for the evaluation of the high-quality cultivation of outstanding innovative talents.

4.Construction of the Evaluation Model of the Core Competency System of Outstanding Innovative Talents

4.1 Establishment of the Evaluation Model

The evaluation of the core competency system of outstanding innovative talents has the characteristics of multi-dimensions, dynamics, and uncertainty. Traditional single evaluation methods are difficult to comprehensively quantify implicit indicators such as innovative ability and practical ability, and are easily interfered by subjective factors. Therefore, this study adopts the grey fuzzy comprehensive evaluation method to construct the evaluation model. This method uses the grey system theory to deal with the problem of "partially known information and partially unknown information" in the evaluation process, and combines the membership degree description of qualitative indicators in fuzzy mathematics, which can effectively evaluate the core competency system of outstanding innovative talents in universities. This model can comprehensively consider multiple evaluation indicators, and obtain the comprehensive evaluation results of the system through the calculation of fuzzy membership degree and grey correlation degree.

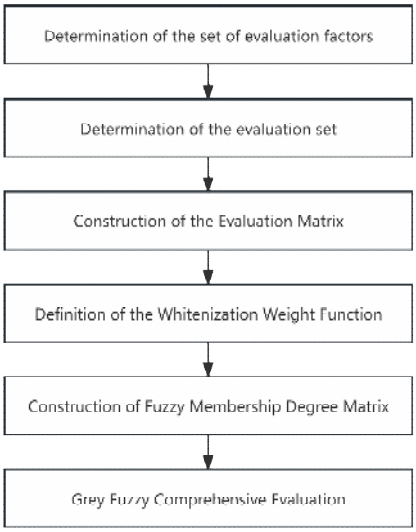

Figure 2.Gray Fuzzy Comprehensive Evaluation Method Flowchart

4.1.1 Construction of the Evaluation Matrix

Organize m (m = 1, 2,..., s) experts to score the indicators of the core competency system of outstanding innovative talents from 0 to 10 according to their experience. The higher the score, the higher the quality level. Then summarize and generalize the scoring results given by all experts to form an expert evaluation matrix.

4.1.2 Definition of the Whitenization Weight Function

Due to the cognitive differences of experts on the evaluation objects, only the whitenization values of grey numbers can be given. Therefore, it is necessary to determine the whitenization weight function to truly reflect the evaluation of experts. In this study, the

evaluation objects are divided into different grey classes according to their grades, and the grey class e = {5, 4, 3, 2, 1} = {very high, high, medium, low, very low} is defined, and the thresholds of each evaluation grey class are set as 10, 8, 6, 4, 2, 0 respectively. The whitenization weight function $f_e(x_{ijm})$ is established to represent the whitenization weight function of the k (k = 1, 2, 3, 4, 5)th grey class of the ijth indicator by the mth expert. According to the relevant research on triangular whitenization weight function grey evaluation, the whitenization weight function is summarized as formula (1).

$$f_k(x_{ijm}) = \begin{cases} 0, & x_{ijm} \notin [x^{k-1}, x^{k+2}] \\ \dfrac{x^{k+2} - x_{ijm}}{x^{k+2} - \lambda^k}, & x_{ijm} \in [\lambda^k, x^{k+2}] \\ \dfrac{x_{ijm} - x^{k-1}}{\lambda^k - x^{k-1}}, & x_{ijm} \in [x^{k-1}, \lambda^k] \end{cases} \tag{1}$$

4.1.3 Construction of Fuzzy Membership Degree Matrix

According to the whitenization weight function, the grey statistics of xijm belonging to $f_e(x_{ijm})$ are calculated respectively, and $q_{ij} = \sum_{m=1}^{s} f_e(x_{ijm})$ after normalization, that is $r_{ije} = q_{ij} / Q_{ij}$, where , Among them, $Q_{ij} = \sum q_{ij}$ obtains the membership vector $r_{ije} = (r_{ij1}, r_{ij2}, r_{ij3}, r_{ij4}, r_{ij5})$ of the Bij index, and synthesizes the fuzzy membership matrix Rij constructed by all indexes.

4.1.4 Grey Fuzzy Comprehensive Evaluation

The evaluation vector of each indicator for the evaluation object in the grey fuzzy comprehensive evaluation is:

$$C_{ij} = W_{ij} ? R_{ij} = (c_{ij1}, c_{ij2}, c_{ij3}, c_{ij4}, c_{ij5}) \tag{2}$$

Where: Cij is the membership degree of the evaluation object to the indicator Bij. Then, according to the quality level standard E = (1, 2, 3, 4) of the top-notch innovative talent training divided by the grey class, the comprehensive evaluation result Y of risk early warning is calculated:

$$Y = E \cdot C_{ij} \tag{3}$$

According to the comprehensive evaluation result, the current status of the top-notch innovative talent training level can be judged, so as to provide reference suggestions for university managers and contribute to the construction of top-notch innovative talent training in universities.

4.2 Application of the Evaluation Model

4.2.1 Establishment of Evaluation Matrix

Taking a certain university as the evaluation object, this paper organizes 10 experts, including teachers, administrative staff, and other relevant position experts, to score the quality indicators of top-notch innovative talent training in the university from 0 to 10 based on teaching and management experience. The scores given by all experts are summarized to form an expert evaluation matrix.

4.2.2 Construction of Fuzzy Membership Degree Matrix

According to the divided grey classes and threshold settings, for the evaluation matrix, the fuzzy membership degree matrix is calculated and normalized according to formula (1), as shown in Table 4.

Table 4.Fuzzy Membership Degree Matrix Table

Number	Indicator	Very low	Low	Medium	High	Very high
F1	Interdisciplinary knowledge	0	0.0000	0.1163	0.4419	0.4419
F2	Professional ability	0	0.0465	0.2558	0.3953	0.3023
F3	Innovation capability	0	0.0000	0.0698	0.4651	0.4651
F4	Critical Thinking	0	0.1364	0.3182	0.3636	0.1818
F7	Global Vision	0	0.1111	0.3333	0.4222	0.1333
F5	Practical ability	0	0.1111	0.3778	0.3778	0.1333
F6	Ethical awareness	0	0.0455	0.3182	0.4545	0.1818
F10	School-Enterprise cooperation	0	0.0000	0.2558	0.5116	0.2326
F12	Adaptability	0	0.0889	0.3333	0.3778	0.2000
F8	Team collaboration ability	0	0.1429	0.4286	0.3333	0.0952
F9	Leadership	0	0.1395	0.4884	0.3488	0.0233
F11	Communication ability	0	0.2727	0.5455	0.1818	0.0000
F13	Professional knowledge	0	0.0455	0.3182	0.4545	0.1818
F14	Engineering knowledge	0	0.0222	0.3778	0.5111	0.0889

It can be seen that the membership degrees of interdisciplinary ability, professional ability and innovative ability under the three indicators at the very high quality level are the highest, while the membership degrees of five indicators including engineering knowledge, school-enterprise cooperation, innovative ability, professional knowledge and ethical awareness in the grey class of high quality level are the highest.

4.2.3 Grey Fuzzy Comprehensive Evaluation

Based on Equation (4) and Equation (5), a grey fuzzy comprehensive evaluation of the core competency system of outstanding innovative talents is carried out. The result is Y = 3.983, as shown in Table 5 specifically. This value is between medium and high quality, and is closer to the high quality state, indicating that, generally speaking, the core competencies of outstanding innovative talents in this university perform well. Combining the results of the grey fuzzy comprehensive evaluation of each indicator, the comprehensive evaluation values of several indicators such as adaptability, humanistic knowledge, communication ability and school-enterprise cooperation are lower than the overall comprehensive evaluation value, and improvements should be made in these aspects.

Table 5.Results of Grey Fuzzy Comprehensive Evaluation

F1	F2	F3	F4	F7	F5	F6	F10
0.1778	0.2178	0.4092	0.2769	0.3463	0.1968	0.2731	0.2704
F12	F8	F9	F11	F13	F14	F15	Total
0.2169	0.2302	0.2894	0.2141	0.3414	0.2882	0.2338	3.9830

4.3 Analysis of Evaluation Results

In this study, a grey fuzzy comprehensive evaluation model of the core competency system for outstanding innovative talents was constructed, and a certain university was selected as the research object to evaluate the core competency system for outstanding innovative talents. Compared with traditional AHP-fuzzy methods, GFCE demonstrates superior robustness and objectivity in comprehensive evaluation results: AHP-fuzzy methods rely on subjective weight assignment by experts, which is prone to individual experience bias and limited in capturing non-linear correlations between indicators. In contrast, GFCE quantifies the dynamic coupling relationship between indicators and evaluation objectives through grey relational analysis, and systematically handles uncertainties in the evaluation process by integrating fuzzy membership functions. This not only reduces the risk of bias from subjective weighting but also enhances the characterization of multi-dimensional indicator interactions. Notably, in scenarios with small samples or incomplete information, the credibility and interpretability of its evaluation results are significantly higher than those of traditional methods.

The evaluation results show that the core competencies of outstanding innovative talents in

this university perform well and the cultivation quality is high. However, continuous improvement and enhancement are still needed in aspects such as adaptability, humanistic knowledge, communication ability, and school-enterprise cooperation, so as to improve the core competency system for outstanding innovative talents and comprehensively enhance the cultivation quality of outstanding innovative talents.

5.Conclusion

Outstanding innovative talents, as the primary resource for the development of new productive forces[22], are the key path for higher education to deal with international competition, achieve scientific and technological self-reliance, and build a powerful education country. In this study, by drawing on the educational concepts and practical experience of world-class universities, an evaluation index system for the core competencies of outstanding innovative talents was constructed, and a certain university was evaluated using the grey fuzzy comprehensive method. The results show that the core competencies of outstanding innovative talents in this university perform well and the cultivation quality is high. However, further improvement and perfection are still needed on the existing basis. The cultivation of outstanding innovative talents should adhere to the cultivation concept of "based on the era and facing the future", and enhance the ability to respond to the challenges of complex international environments and major scientific research technologies; establish a professional system of "thick general knowledge, strong interdisciplinary integration, and multiple composites" to improve students' ability to solve complex engineering problems; strengthen the evaluation model of "demand-oriented, problem-oriented, and result-oriented" to promote the iterative optimization of the talent cultivation process; create a cultivation ecology of "school-enterprise cooperation, diversified coordination, and integration of industry and education", and strive to cultivate students into outstanding innovative talents who can meet the development needs of new productive forces, serve national strategies, and promote scientific and technological innovation.

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