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Research on the Coupling and Coordination of Education Digitization and Higher Education Development

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Abstract: Digitalization of education is an important breakthrough to open up a new pathway of education development and shape a new advantage of education transformation. This study takes the development of higher education and the digital transformation of education as the research object. First, using the Entropy Weight Method, the development level of higher education and the digitalization level of education in 31 provincial administrative regions in China are measured. Moreover, by calculating the coupling degree and coordination degree between the two through the Coupling Coordination Analysis Model, the advantages and disadvantages of educational digital transformation and higher education development in various provinces are revealed. Ultimately, it provides data support and decision-making basis for the formulation of policies and resource allocation related to educational digital transformation and high-quality development of higher education.

1. Introduction

Digital resources in higher education are a core element of educational modernization, interacting with the development level of higher education to form a complex two-way interactive relationship [1]. The richness and accessibility of digital resources have a direct impact on teaching quality and research efficiency, promoting teaching innovation and personalized learning to meet the needs of students' all-round development. At the same time, the integration and analysis capabilities of digital resources provide new tools for scientific research, accelerating knowledge innovation and dissemination. The high-quality development of higher education relies on the supply of digital resources and also involves the transformation of educational concepts, requiring educators to use digital resources to promote the development of students' critical thinking and creativity, which are important indicators for measuring educational levels [2]. Meanwhile, the improvement of the development level of higher education also provides impetus and direction for the further development and application of digital resources [3]. The demand for high-quality education has prompted policymakers and educational managers to attach importance to digital resources, thereby providing policy and funding inclinations to promote the construction and optimization of digital resources.

In addition, in the process of pursuing high-quality development, higher education institutions have cultivated and attracted a group of talents capable of innovating and improving digital resources,

providing intellectual support for the sustainable development of digital resources. At the provincial level, the relationship between the development level of higher education and the allocation of digital resources reflects the efficiency of educational resource allocation and utilization. If a province has a high level of higher education development and abundant digital resources, it indicates that it has high efficiency in resource allocation. Conversely, if the development level is low but digital resources are abundant, it shows that the province has potential in resource utilization. If both perform poorly, it indicates that the province has obvious deficiencies in educational resource allocation and development. Finally, if the level of higher education development is high but digital resources are scarce, it may indicate an imbalance in resource allocation that needs further optimization. The synergistic relationship between the quantity of digital resources in higher education and the development level is dynamically complex. It reflects in the direct impact of the quantity of digital resources on educational quality and the reaction of the educational development level on resource supply and optimization. Incorporating the quantity of digital resources into the development level of higher education to establish an evaluation system is conducive to guiding policy formulation and resource allocation, solving resource allocation problems, and promoting the balanced and high-quality development of higher education.

This study calculates the comprehensive scores of higher education development level and educational digitalization development level in 31 provincial administrative regions in China through the Entropy Weight Method, and reveals the advantages and disadvantages of educational digital transformation and higher education development in each province through Coupling Coordination Analysis Model, and then to analyse the coupling degree and coordination degree between the two.

2. Methods

2.1. Entropy Weight Method

This study adopts the entropy weight method to conduct a comprehensive evaluation of the level of educational digitalization and higher education development in various regions. The entropy weight method, which first emerged from the basic principles of information theory, is a mathematical method that objectively calculates the weight of each indicator by comprehensively considering the amount of information provided by various factors. Its advantage lies in its ability to objectively and accurately reflect the amount of information and the degree of variation of each indicator. The basic idea of the entropy weight method is to determine the objective weight based on the degree of variability of the indicators [4]. Generally speaking, if the information entropy of an indicator is smaller, it indicates that the degree of variation in the indicator values is greater, the amount of information provided is more, the role it can play in the comprehensive evaluation is more significant, and thus its weight is larger. Conversely, if the information entropy of an indicator is larger, it means that the degree of variation in the indicator values is smaller, the amount of information provided is less, the role it plays in the comprehensive evaluation is smaller, and therefore its weight is smaller.

2.2. Coupling Coordination Analysis Model

Coupling refers to a phenomenon where two or more systems influence each other through interaction. Coupling degree refers to the extent to which systems influence each other, and coupling coordination degree refers to the degree of benign coupling in the interaction between systems, reflecting the quality of coordination [5]. Coupling is used to indicate the intensity of interaction between different systems. A larger coupling coordination value means a stronger intensity of interaction between systems [6]. The calculation method of the coupling degree C value is as follows:

$$C(U_1, U_2, U_3, U_4, \dots U_n) = n\left[\frac{U_1 U_2 U_3 U_4 \dots U_n}{(U_1+U_2+U_3+\dots+U_n)^n}\right]^{\frac{1}{n}} \quad (1)$$

In the above formula, the value of U represents the system data, and n denotes the number of systems. After obtaining the coupling degree value C, the coordination degree value T can be calculated, and its calculation formula is as follows:

$$T = \beta_1 U_1 + \beta_2 U_2 + \beta_3 U_3 + \dots + \beta_n U_n \quad (2)$$

In the above formula, β represents the weight value of the system, and U is the system data. If the weights of each system are consistent, then all β values are $1/n$, where n is the number of systems. If the weight values of each system are different, this value can be set. After calculating the coupling degree value C and the coordination degree value T, the final coupling coordination degree value D can be calculated, and its calculation formula is as follows:

$$D = \sqrt{C \times T} \quad (3)$$

It can be known from the above formula that the value of $C \times T$ cannot be less than 0. For this reason, it is generally hoped that both the C value and the T value are greater than 0 to ensure the normal calculation of the D value. Both the C value and the T value are calculated based on the U value, that is, the system data. Therefore, in general, it is necessary to process the data in advance to ensure that the U value is greater than 0, so as to prevent the failure to calculate the coupling coordination degree D value. After calculating the D value, combined with the value range of the D value, the coordination level and coupling coordination degree of each item are calculated. There is a one-to-one correspondence between the coordination level and the coupling coordination degree [7], as shown in Table 1 and Table 2.

Table 1: Classification criteria for coupling coordination degree levels.

Item	Value Range	Category	Item	Value Range	Category
Coupling Degree Value C	0.0<C≤0.3	Stage of Low-level Coupling	Coupling Coordination Degree D Value	0.0<D≤0.3	Low Coordination Coupling Type I
	0.3<C≤0.5	Antagonistic Stage		0.3<D≤0.5	Moderate Coordination Coupling Type II
	0.5<C≤0.8	Running-in Stage		0.5<D≤0.8	High Coordination Coupling Type III
	0.8<C≤1.0	Stage of High-level Coupling		0.8<D≤1.0	Extreme Coordination Coupling Type IV

Table 2: Interval of coupling coordination degree and classification criteria for coordination levels.

Interval of Coupling Coordination Degree D value	Level	Category
[0.0~0.1)	1	Extreme Imbalance
[0.1~0.2)	2	Severe Imbalance
[0.2~0.3)	3	Moderate Imbalance
[0.3~0.4)	4	Mild Imbalance
[0.4~0.5)	5	Near Imbalance
[0.5~0.6)	6	Barely Coordinated
[0.6~0.7)	7	Primary Coordination
[0.7~0.8)	8	Intermediate Coordination
[0.8~0.9)	9	Good Coordination
[0.9~1.0]	10	High-quality Coordination

2.3. Evaluation index system

The higher education system is complex, and the academic community has not yet unified the

evaluation indicators. Some research focus on stock and increment to construct an evaluation system for the scale, structure, and conditions of higher education [8]. Some research builds multi-level indicators such as human resources and material resources from the perspective of resources [9]. And others consider the quantitative and qualitative dimensions to explore the problems and solutions in underdeveloped areas of higher education [10]. The number of people and scale are the core indicators for measuring the quantity of higher education. In the popularization stage, educational quality is becoming increasingly important, and digital empowerment aims to promote the high-quality development of higher education [11]. Therefore, this study intends to construct an evaluation index system that covers both the quantity and quality of higher education.

In terms of quantity evaluation, it covers three dimensions: school scale, student quantity, and teacher quantity. The school scale includes the average number of undergraduate, junior college, and key colleges and universities per 10,000 people; the student quantity covers the average number of undergraduate, junior college, and postgraduate students per 10,000 people; the teacher quantity involves the relative scale of full-time teachers and faculty and staff in ordinary colleges and universities. In the quality evaluation, a comprehensive index system is constructed around educational funds, teaching staff, and school-running conditions. For funds, attention is paid to the growth trend of per-student general public budget funds and the growth of educational operating expenses and public funds expenditure; for school-running conditions, focus is on hardware facilities and resource allocation, which are reflected through per-student floor area, school building area, and fixed assets, etc. The evaluation system is detailed in Table 3.

Table 3: Comprehensive Evaluation Index Framework for the Digital Education and Higher Education.

First-level Indicator	Secondary Indicator	Tertiary Indicator	Unit
Digitalization of Education	Virtual Digital Resources	E-Books (Per Student)	Book
		E-Journals (Per Student)	Book
		Degree Thesis (Per Student)	Book
		Audio and Video (Per Student)	Hour
		Simulation Training software	Set
		Simulation Practice software	Set
	Physical Digital Resources	Number of Terminals (Per Student)	Set
		Number of Terminals (Per Teachers)	Set
		Network Multimedia Classroom (Per Student)	Room
Higher Education	Quantity of Higher Education	Academic HEIs	Institution
		Professional HEIs	Institution
		Vocational HEIs	Institution
		HEIs under Central Ministries and Agencies	Institution
		Number of Postgraduate Students Per 10,000 People	Person
		Number of Regular Undergraduate Students in Higher Education Per 10,000 People	Person
		Number of Vocational Undergraduate and Junior College Students in Higher Education Per 10,000 People	Person
		Number of Online Undergraduate and Junior College Students in Higher Education Per 10,000 People	Person
	Quality of Higher Education	Average General Public Budget Education Fund (Per Student)	Yuan
		Proportion of Full-time Teachers with Doctoral Degrees in Regular Institutions of Higher Education	%
		Average School Area (Per Student)	m^2
		Average School Building Area (Per Student)	m^2
		Fixed Asset (Per Student)	10000 Yuan

3. Results

3.1. Measurement Results of Digital education and Higher Education Development Level

Relevant data for the evaluation of educational digital transformation and higher education development level are derived from public reports released by authoritative institutions such as the Ministry of Education, the National Bureau of Statistics, the National Development and Reform Commission, and the Ministry of Finance (only the statistical results of 2021, 2022, and 2023 are publicly available for the data required in this study). The entropy weight method is used to determine the weights of the evaluation indicators for educational digitalization and higher education development level, and the comprehensive scores of educational digitalization and higher education development level are calculated respectively. The specific measurement results are as follows.

From the measurement results of educational digitalization in each province (Figure 1), it can be seen that from 2021 to 2023, the educational digitalization level of each province has been improved to varying degrees. That is, the educational digitalization level of each province in 2023 is higher than that in 2021 and 2022. Looking at the specific situations of each province, the level of educational digital transformation shows significant differences. From 2021 to 2023, the educational digitalization levels of Beijing, Jiangsu, Zhejiang, and Chongqing have been at the forefront of the China. In 2023, the educational digitalization level of Guangdong Province has risen to the top 5 in the country. In addition, from 2021 to 2023, the educational digitalization degrees of Ningxia, Gansu, and Qinghai provinces are slightly lower than those of other provinces in China. Generally speaking, each province is implementing educational digital transformation to varying degrees, but the degree of transformation shows regional differences. Economically developed regions also have a relatively high degree of educational digital transformation, while the educational digitalization of provinces in economically underdeveloped regions still needs to be developed.

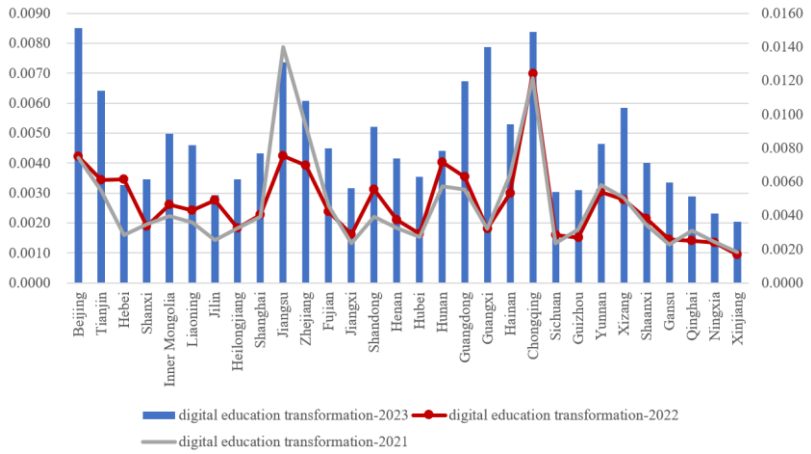

Figure 1: Educational Digital Transformation in 2021, 2022, and 2023.

From the measurement results of educational digitalization across provinces (Figure 2), starting from 2021, the higher education development levels of Beijing, Shanghai, Shaanxi, Jiangsu, and Tianjin have remained at the forefront of the country. In 2023, Guangdong entered the top 5 nationwide. Similarly, this study pays close attention to provinces with relatively underdeveloped higher education. Specifically, from 2021 to 2023, Henan, Inner Mongolia, and Anhui Province ranked relatively low in the national higher education development rankings, while Yunnan and Guizhou Province emerged from their previously backward positions in 2023. Overall, the higher education development level of all provinces has shown an improving trend over time, but the differences in the trends of higher education development are very prominent. This is reflected in the

fact that the capital city (Beijing) stands out alone, while there are gaps in both the quantity and quality of higher education between marginal regions and the capital city as well as economically developed areas.

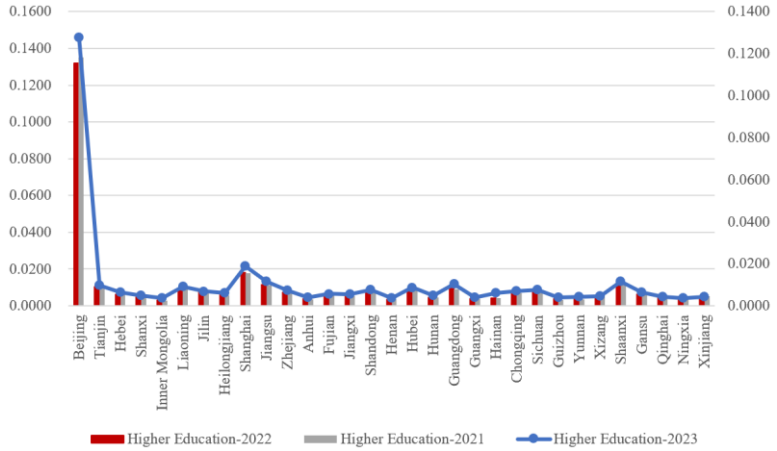

Figure 2: Higher Education Development Level in 2021, 2022, and 2023.

3.2. Results of Coupling Coordination Degree

Table 4: Measurement Results of Coupling Coordination Degree.

Province	C	T	D
Beijing	0.365	0.484	0.420
Tianjin	0.918	0.043	0.199
Hebei	0.913	0.026	0.154
Shanxi	0.980	0.020	0.140
Inner Mongolia	0.986	0.018	0.134
Liaoning	0.884	0.038	0.182
Jilin	0.882	0.027	0.154
Heilongjiang	0.931	0.025	0.153
Shanghai	0.670	0.074	0.222
Jiangsu	0.903	0.052	0.216
Zhejiang	0.963	0.034	0.181
Anhui	0.997	0.02	0.140
Fujian	0.975	0.025	0.157
Jiangxi	0.947	0.022	0.145
Shandong	0.938	0.034	0.178
Henan	0.999	0.018	0.132
Hubei	0.849	0.035	0.172
Hunan	0.992	0.022	0.148
Guangdong	0.913	0.046	0.205
Guangxi	0.969	0.025	0.156
Hainan	0.981	0.028	0.165
Chongqing	0.996	0.036	0.190
Sichuan	0.857	0.030	0.161
Guizhou	0.993	0.017	0.129
Yunnan	1.000	0.020	0.141
Shaanxi	0.793	0.046	0.191
Gansu	0.924	0.025	0.153
Qinghai	0.986	0.017	0.129
Ningxia	0.991	0.014	0.118

After separately measuring the higher education development level and the degree of educational digital transformation in each province of the study area, this study adopts the coupling coordination degree model to explore the coupling coordination relationship between the higher education development level and educational digitalization in each province. The measurement results are shown in Table 4.

As can be seen from Table 4, the coupling degree between the higher education development and educational digital transformation in all provinces are relatively high, ranging from 0.365 to 1. And the coupling degree values between the two systems (higher education development level and educational digital transformation) in most provinces are above 0.8. However, the coupling coordination degree values are relatively low, ranging from 0.118 to 0.42. For the analysis of coupling degree and coupling coordination degree, the definition of the category to which the coupling coordination degree belongs is more important than the analysis of absolute values. Therefore, based on the calculation results of coupling degree and coupling coordination degree between higher education development level and educational digital transformation in each province, and in accordance with the standards for dividing coupling coordination degree intervals and coordination levels in Table 1 and Table 2, the categories are defined, and the results are shown in Table 5.

Table 5: Results of Coupling Coordination Category.

C	Province	D	Province
Stage of Low-level Coupling	None	Near Imbalance	Beijing
Antagonistic Stage	Beijing	Mild Imbalance	None
Running-in Stage	Shaanxi	Moderate Imbalance	Shanghai; Jiangsu; Guangdong
Stage of High-level Coupling	Tianjin; Hebei; Shanxi; Inner Mongolia; Liaoning; Jilin; Heilongjiang; Shanghai; Jiangsu; Zhejiang; Anhui; Fujian; Jiangxi; Shandong; Henan, Hubei; Hunan; Guangdong; Guangxi; Hainan; Chongqing; Sichuan; Guizhou; Yunnan; Gansu; Qinghai; Ningxia	Severe Imbalance	Tianjin; Hebei; Shanxi; Inner Mongolia; Liaoning; Jilin; Heilongjiang; Zhejiang; Anhui; Fujian; Jiangxi; Shandong; Henan, Hubei; Hunan; Guangxi; Hainan; Chongqing; Sichuan; Guizhou; Yunnan; Shaanxi; Gansu; Qinghai; Ningxia

It can be seen from Table 5 that except for Beijing and Shaanxi, the coupling degree between educational digital transformation and higher education development level in all other provinces is in the stage of high-level coupling, which means there is a strong interaction between the two. In terms of coupling coordination degree, except for Beijing, Shanghai, Jiangsu and Guangdong, the educational digitalization and higher education in most provinces are in a stage of severe imbalance. That is, the educational digitalization is not synchronized with the development level of higher education. Although the degree of educational digitalization is gradually improving, the speed and quality of its transformation still cannot fully adapt to the development of higher education.

4. Conclusions

Based on the provincial-level educational digital transformation and higher education development level in China, this study constructs an indicator system covering virtual digital resources and physical resources, and uses the entropy method to measure the degree of provincial educational digital transformation. It also measures the provincial higher education development level by building an indicator system that includes the quantity and quality of higher education. On this basis, the coupling coordination degree model is adopted to explore the relationship between educational digitalization and higher education development. The findings are as follows:

First, the higher education development level of each province is basically consistent with its economic development level. Regions with more developed economies also rank among the top in the country in terms of the degree of educational digital transformation.

Second, the degree of educational digital transformation in each province has a strong correlation with national policy inclination. The abundance of digital resources and their matching degree with the development of higher education essentially reflect the strategies and effectiveness of resource allocation by the country, provinces and universities.

Third, at present, the degree of educational digital transformation has not kept pace with the development level of higher education. In terms of high-quality development of education, the degree of educational digital transformation still needs to be improved.

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