ARTICLE

Evaluation of the Development Level of Information and Communications Technology in Education Based on the Entire-Array-Polygon Indicator Method: Taking the Questionnaire Survey Data of 13 Cities in Province W as an Example

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Abstract. *The objective assessment of the development level of information and communications technology (ICT) in education can support the government in formulating and implement ICT policies. The article first introduced the Entire-Array-Polygon (EAP) indicator method and then designed an evaluation indicator system which containing five first indicators and 31 secondary indicators. Finally, using the questionnaire survey data of 13 cities in Province W as an example, the EAP indicator method was used to carry out on the evaluation of ICT development level. The study drew the following conclusions: EAP indicator method can objectively assess the development level of ICT; the overall development level of ICT in the 13 cities in Province W is average and above, and most of them are level II. When using the EAP indicator method to assess the development level of ICT, experts do not need to determine the indicator's weight. Also, this method presents the evaluation results more concisely and intuitively, so it can be promoted as an essential method of evaluating on the development level of ICT in education.*

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Introduction

THE evaluation of ICT is an important of the development of ICT in Education, runs through the entire its construction process and is an essential guarantee for its healthy and orderly development (Xu et al., 2018). Through the evaluation, the implementation of related planning and policies can be clarified, and then the problems in the process can be found, which provides a basis for its formulation of the next stage of planning and resource allocation (Wu et al., 2017). The evaluation of its development level is a multi-attribute comprehensive assessment. Its purpose is to assess the status quo of ICT development, clarify development needs, and provide a basis for developing development plans or goals for the next stage. The evaluation process is complicated, and the objects involve educational administrative departments, schools, teachers, and students (Wu et al., 2018).

The main methods for its evaluating on the development level include the Analytic Hierarchy Process and the Delphi method (Lv & Ke, 2020; Yin et al., 2020). However, in using these methods to evaluate on its development level, the determination of indicator weights is subjectively arbitrary, which leads to deviations between the evaluation results and the actual situation. This study introduces the EAP indicator method into the ICT development level evaluation in response to the above problems.

Entire-array-polygon (EAP) indicator method is an objective, comprehensive evaluation method. There is no need to subjectively determine each indicator's weight value in the evaluation process, which can reduce subjective factors' influence on the evaluation results and make the evaluation results more objective and accurate (Wu et al., 2005). Also, this method presents the evaluation results more concisely and intuitively. There are both single index value and comprehensive index value, which is convenient to reflect the evaluation object's comprehensive status objectively. This study uses the questionnaire survey data of 13 cities in Province W as an example and uses this method to evaluate the development level of ICT. It is expected to reference Province W's relevant departments to formulate ICT development plans or goals.

EAP Indicator Method

The EAP indicator method is a comprehensive evaluation of the object evaluated based on the relationship between the upper limit, critical value, and lower limit of the evaluation index value. And then realize the vertical and horizontal comparison of the same index or dimension (Kosajan et al., 2018). The basic idea is as follows: Suppose there are a total of n indicators (standardized values), and use the upper limit value of these indicators as the radius to construct a central n-sided polygon whose vertices are a full array of n indicators connected end to end. There are a total of n indicators that can form (n-1)!/2 irregular central n-sided polygons. The comprehensive index is defined as the ratio of the mean value of the area of all irregular polygons to the area of the central polygon.

Standardization of Indicators

The standardization of the indicators can be realized by the hyperbolic function f(x), as shown in formula (1). Among them, a, b, and c are the parameters of f(x).

$$f(x) = \frac{a(x+b)}{x+c}, a \neq b, x \geq 0 \qquad (1)$$

According to the above conditions, the hyperbolic standardized function F(x) can be obtained, as shown in formula (2). Among them, U represents the upper limit of indicator x, L represents the lower limit of indicator x, T represents the critical value of indicator x (usually the mean value), F(x) satisfies F(L) = -1, F(T) = 0, F (U) = 1. F(x) maps the index value between L-U to between -1 and 1. The growth rate after the mapping has changed: when it is lower than the critical value, the standardized growth rate gradually decreases; when it is higher than the critical value, the standardized growth rate gradually increases.

$$F(x) = \frac{(x+b)(x-T)}{(U+L-2T)x+UT+LT-2UL}, a \neq 0, x \geq 0 \qquad (2)$$

According to the EAP indicator method's basic idea, each indicator needs to be standardized before calculating the comprehensive index. The standardization process of indicator xi is shown in formula (3). S_i is a standardized value of the indicator, and U_i, L_i, and T_i are the maximum, minimum, and average values of the indicator x_i, respectively.

$$S_i = \frac{(U_i-L_i)(x_i-T_i)}{(U_i+L_i-2T_i)x_i+(U_i+L_i)T_i-2U_iL_i} \qquad (3)$$

Comprehensive Index Calculation

After the indicators are standardized, the total index S value can be calculated by the formula (4). S_i is the i-th indicator value, S_j is the j-th indicator value ($i \neq j$), and n is the number of indicators. According to the basic idea of the EAP indicator method, S's value is between [0, 1], and the larger the value of S, the better.

$$S = \frac{\sum_{i\neq j}^{i,j}(S_i+1)(S_j+1)}{2n(n-1)} \qquad (4)$$

Based on the EAP indicator method's quartile classification standard, the ICT development level can be divided into four levels: I, II, III, and IV, which represent excellent, good, fair, and poor, respectively in **Table 1**.

Table 1. ICT in Education Development Level Classification.

Level	I	II	III	IV
S Value	[0.75, 1.00]	[0.50, 0.75)	[0.25, 0.50)	[0.00, 0.25)
Qualification	Excellent	Good	Fair	Poor

Design of ICT in Education Development Level Evaluation Indicator System

This research follows scalability, accessibility, and comprehensiveness and has designed an evaluation indicator system of ICT development level. The formation process is as follows:

(i) Construction of Core Indicator System. Based on the development strategy needs of China's "ICT Ten-Year Development Plan (2011-2020)", "ICT 13th Five-Year Plan" and other documents and its exact requirements for core indicators, it refers to the typical foreign School Technology and Readiness Chart (STaR) , the Self-Review Framework (SRF) and ICT application maturity model (Texas Education Agency, 2006; BECTA, 2009; Solar et al., 2013). This study proposed a core indicator system of ICT with 32 indicators in five dimensions: ICT infrastructure, digital resources, ICT usage, ICT management, and guarantee mechanisms (Wu, et al., 2014).

(ii) This study supplemented ICT development level evaluation's scalability indicators based on this ICT core indicator system, combined with the current research status of ICT development level evaluation in domestic and overseas. Taking the eastern Province S as an example, research on ICT performance evaluation at the district and county level was carried out (Lu et al., 2015).

(iii) According to the development requirements of the ICT 2.0 stage, the core indicator system will be further improved. Based on the expanded core indicator system, combined with the requirements of Province W's 2019 related policy documents, this research organizes experts, education management leaders, school ICT managers, and frontline teachers to focus on the availability and comprehensiveness of individual indicators discussion.

This study has constructed an evaluation indicator system of its development level with five primary indicators and 31 secondary indicators through the above steps. It is used to evaluate the development level of ICT in Province W (Wu et al., 2020), as shown in **Table 2**.

The Evaluation Case of ICT in Education Development Level Based on EAP Indicator Method

Table 2. ICT in Education Development Level Evaluation Index System.

First-Level Index	Secondary Indicators
Infrastructure	1. Proportion of multimedia classrooms
	2. Proportion of schools with innovative laboratories
	3. Average number of terminals per 100 students
	4. Number of teaching information terminals held by teachers
	5. Percentage of schools connected to the Internet
	6. Proportion of schools with full coverage of wireless networks in schools
Digital Resources	7. Proportion of schools with digital resources supporting disciplines
	8. Proportion of schools with a school-based resource database
	9. Proportion of schools with online space
	10. Percentage of students who have opened a student online learning space
	11. Percentage of teachers who have opened teacher online learning space
	12. Proportion of schools connected to the public service platform of provincial education resources
Teaching Application	13. Proportion of schools with normalized application of school cyberspace
	14. Proportion of schools with all classes able to use digital education resources
	15. Proportion of schools that can use information technology to teach and achieve daily routines
	16. The proportion of teachers who frequently use multimedia teaching resources in teaching
	17. Average utilization rate of multimedia classrooms
	18. The average number of lessons per teacher in the past year
Management Informatization	19. Proportion of schools with normalized application of management information system
	20. Proportion of schools carrying out the application of basic data of management information
	21. Proportion of schools that use school-level public service platforms to release information
	22. Proportion of schools with cyber security systems
	23. Proportion of schools with full coverage of the campus by the security monitoring system
	24. have a school proportion cartoon
	25. School informatization funds accounted for the proportion of education funds in the same period
Guarantee Mechanism	26. Proportion of schools with school-level leaders in charge of informatization construction
	27. The proportion of teachers who participated in school-based information training in the past year
	28. Proportion of schools where school leaders participate in informatization training at or above the provincial level
	29. Percentage of schools with full-time teachers of information technology courses
	30. Proportion of schools with full-time informatization personnel
	31. Proportion of schools implementing measures to improve teachers' information technology application capabilities

The ICT development level is mainly characterized by the dimension index and the comprehensive index. The EAP indicator method is used to measure and calculate the index value. It is derived based on the upper limit, lower limit, the critical value of each indicator, and the relationship between them, so that horizontal or vertical comparison between indexes can be realized. For the multi-dimensional, multi-level, and relatively complex systematic assessment of the development level of ICT, the EAP indicator method can be used to realize the assessment object's mapping from high-dimensional

Table 3. Evaluation Results of ICT in Education Development Level and Its Classification.

City Code	ICT Dimension Index (Level)					ICT Comprehensive Index (Level)
	Infrastructure	Digital Education Resources	Teaching Application	Management Information	Guarantee Mechanism	
W1	0.74 (II)	0.85 (I)	0.64 (II)	0.56 (II)	0.74 (II)	0.74 (II)
W2	0.45 (III)	0.24 (IV)	0.49 (III)	0.74 (II)	0.26 (III)	0.43 (III)
W3	0.73 (II)	0.42 (III)	0.80 (I)	0.37 (III)	0.33 (III)	0.54 (II)
W4	0.67 (II)	0.61 (II)	0.65 (II)	0.82 (I)	0.74 (II)	0.72 (II)
W5	0.55 (II)	0.81 (I)	0.64 (II)	0.77 (I)	0.96 (I)	0.74 (II)
W6	0.30 (III)	0.58 (II)	0.42 (III)	0.23 (IV)	0.16 (IV)	0.34 (III)
W7	0.44 (III)	0.20 (IV)	0.32 (III)	0.46 (III)	0.72 (II)	0.46 (III)
W8	0.15 (IV)	0.80 (I)	0.56 (II)	0.17 (IV)	0.30 (III)	0.36 (III)
W9	0.19 (IV)	0.37 (III)	0.39 (III)	0.23 (IV)	0.46 (III)	0.34 (III)
W10	0.23 (IV)	0.28 (III)	0.30 (III)	0.27 (III)	0.21 (IV)	0.27 (III)
W11	0.66 (II)	0.59 (II)	0.50 (II)	0.81 (I)	0.68 (II)	0.67 (II)
W12	0.63 (II)	0.59 (II)	0.47 (III)	0.65 (II)	0.64 (II)	0.61 (II)
W13	0.47 (III)	0.43 (III)	0.36 (III)	0.86 (I)	0.33 (III)	0.49 (III)
Average	0.48 (III)	0.52 (II)	0.50 (II)	0.53 (II)	0.50 (II)	0.52 (II)

to low-dimensional space. Map 31 second-level indicators to 5 first-level indicators, map from 5 first-level indicators to a comprehensive index, and obtain the classification and ranking information of the evaluation object in the low-dimensional space. In the entire development level evaluation process, there was no need to subjectively determine the weights of the 31 secondary indicators to make the evaluation results more objective, scientific, and reasonable.

This study used the questionnaire survey data of 13 cities in Province W as an example, using the EAP indicator method to evaluate its development level of Province W comprehensively. By comparing and analyzing its development level and classification of 13 cities in Province W, it is possible to fully grasp the ICT development status of Province W. This provides a reference for the formulation and implementation of ICT policy plans in the next phase.

Data Sources

This research has compiled the "elementary and middle school ICT development status survey questionnaire based on this index system." The content includes necessary information, ICT infrastructure, digital resources, ICT teaching application, ICT management informatization, and guarantee mechanism. To objectively reflect the development status of elementary and middle school ICT construction and application, each item is set as an objective question, and the question types are fill-in-the-blank, singleanswer, and multi-answer multiple-choice. In October 2019, this study adopted the stratified random sampling method and carried out a one-month questionnaire survey through the online questionnaire. The questionnaire was filled out by the person in charge of the elementary and middle school ICT work in 13 cities in Province W (such as principals, directors of ICT centers). After the survey, the study received 5,968 questionnaires, of which 5,285 were valid, and the effective rate was 88.56%.

Evaluation Results and Analysis

This study's operation process to evaluate its development level of Province W was as follows: (i) According to the related evaluation indicator system, the original values of 31 secondary indicators were calculated using Excel. (ii) Regarding the maximum, minimum, and average values of each secondary indicator as to the upper limit, lower limit, and critical value, respectively, using the R Software, standardize each secondary indicator according to formula (3), and calculate each secondary indicator's standardized value. (iii) Calculate the ICT dimension index value and the comprehensive index value of 13 cities in Province W according to the standardized value of each secondary indicator, using the R software and formula (4); and according to the value range of S in **Table 1**, the ICT development level of 13 cities in Province W was classified.

The specific development level assessment results and their classification are shown in **Table 3**. It shows that the ICT development level of the 13 cities in Province W is generally average or above. Among them, W1 has the highest level of ICT development. The main reason is that W1 is a provincial capital city with a relatively good level of economic development. Chen et al. showed that the regional economy is the necessary foundation for its development (Chen & Zhi, 2018). Therefore, the right economic conditions provide adequate support for W1's development.

Among the five first-level indicators, the dimension index of ICT infrastructure was relatively low. It is the supporting condition for the development and provides a fundamental guarantee for schools to carry out ICT teaching and management. The development of infrastructure in Province W is relatively low, with mobile terminals accounting for only 7.34% of students' ICT terminals, and the average number of terminals per 100 students is only 6.77. This can only meet some students' needs to use ICT to carry out learning activities, and to a certain extent, hinder the school's ICT application level.

In terms of digital resources, Province W has developed well. Among them, W1 has the highest level of development of digital resources. The main reason is that W1 is a national education cloud pilot city, and its convenient education cloud services provide support for the construction and application of digital resources. ICT usage is the focus of ICT construction and a necessary means to improve teachers' and students' information literacy. Province W has developed well in terms of teaching application. At present, 90.21% of elementary and middle schools in Province W can realize the normalized application of ICT to assist teaching of Chinese, mathematics, and English in classroom Some cities have even reached 98.89%.

ICT management is a crucial way to promote the modernization of the school governance system and governance capabilities. The average value of the ICT management index of 13 cities in Province W is the highest (up to 0.53), indicating that Province W has developed well in school ICT management such as management data applications, campus all-in-one cards, and network security systems. The survey data also shows that 7.29% of elementary and middle schools in Province W use campus all-in-one cards, and 77.04% of elementary and middle schools have achieved full coverage of the campus network through the application of security monitoring systems (such as school gates, teaching buildings, and office areas).

The guarantee mechanism is the foundation of its development and the key to the implementation of ICT-related plans. Province W has developed well in terms of guarantee mechanisms. Over 92.86% of elementary and middle schools are supervised by school-level leaders in the construction of ICT in schools, which has promoted ICT in teaching and management to a certain extent. In turn, the overall level of ICT in schools development has been improved.

Conclusions

This study introduced the EAP indicator method into the evaluation of its development level. Based on the questionnaire survey data of the ICT development status of and middle schools in 13 cities in Province W, the ICT development level of Province W was comprehensively evaluated. Furthermore, each city's evaluation results were graded, and the development status of ICT in each city was compared and analyzed. The main conclusions obtained are as follows:

The EAP indicator method can objectively assess the development level of ICT. The EAP indicator method is a quantitative comprehensive evaluation method whose evaluation results are less affected by subjective factors. When using this method to evaluate the development level of ICT, experts are not needed to determine the weights of indicators; only the upper limit, lower limit, and critical value related to decision-making should be determined. This reduces the subjectivity in the evaluation process to a certain extent to reflect the current development of ICT more objectively. Simultaneously, the EAP indicator method presents the evaluation results of the ICT development level only and intuitively. It has both a single indicator value and a total indicator value, which provides convenience for problem diagnosis and policy guidance. Meanwhile, the EAP indicator method is simple and easy to understand, and the calculation process is simple. The EAP indicator method is also convenient to use a computer for programming to realize the participating factors' quantitative processing.

The overall development level of ICT in 13 cities in Province W is average and above, and most of them are at level II. Among them, the digital resources dimension and the ICT management dimension have developed well, the ICT usage dimension and the guarantee mechanism dimension have developed generally, and the ICT infrastructure dimension has developed relatively weakly. To further improve ICT development, an elementary and middle school in Province W should focus on constructing school ICT infrastructure. This ensures that the school has a good ICT teaching and management environment and supports teachers and students to use ICT to carry out teaching and management activities. Simultaneously, it is also necessary to carry out certain targeted and practical teacher ICT training activities to comprehensively improve the elementary primary and middle school teachers' ability to use ICT to carry out teaching. Besides, various forms of ICT training activities such as "school-based training" and "short-term concentrated training" can also be carried out to focus on improving elementary and middle school teachers' ICT teaching design and curriculum resource integration capabilities.

The above conclusions show that the use of the EAP indicator method can objectively and comprehensively evaluate the development of ICT in Province W and can achieve the purpose of horizontal and vertical comparison of the ICT development level of 13 cities in Province W. Besides, the EAP indicator method also reduces the subjectivity in the evaluation process to a certain extent, making the evaluation results concise and intuitive. However, due to the limited survey time, the questionnaire survey data was discontinuous in time. This study did not research time series, so the dynamic assessment of ICT development level from a time perspective will focus on subsequent research.

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