Research on the Measurement Method of Learners' Comprehensive Quality Based on Intuitionistic Fuzzy Entropy

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Abstract. China is actively promoting education reform and high-quality development, emphasizing that comprehensive quality has become the cornerstone of future teaching activities in China, and it has also become one of the essential core literacy for primary and secondary school. Evaluation, as an important component of educational activities, is crucial in constructing a scientific, rational, and innovative educational evaluation system to enhance education quality. Establishing a comprehensive quality evaluation system and implementing it is a key foundation for cultivating and enhancing comprehensive quality, which can also promote students' overall development. In view of the above situation, this paper will combine theoretical research and practical application to attempt to construct a new intuitionistic fuzzy entropy. The aim is to provide new ideas and methods for addressing the difficulties faced by comprehensive quality evaluations and realize the practical application of comprehensive quality evaluations. This will provide theoretical support and practical reference for enhancing and nurturing the comprehensive quality of primary and secondary school.

Keywords: intuitionistic fuzzy entropy, comprehensive quality evaluation, TOPSIS, multi-attribute decision-making.

1 Introduction

The five-education integration has emerged as one of the most representative new trends and directions in the transformation and development of basic education in China since entering a new era. On the path of the new era, we need to make joint efforts and forge ahead toward all-round development in morality, intelligence, physical fitness, aesthetics, and labor. However, the current education system is characterized by phenomena such as neglecting morality, favoring intelligence, weakening physical fitness, suppressing aesthetics, and lacking labor, leading to one-sided development and one-sided education, a departure from the educational principle of all-round development and all-round education[1]. Chinese education in the new era is characterized by moral

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education and talent cultivation, as well as the development of students' comprehensive qualities. To improve the quality of education, it is essential to create an education system that integrates morality, intelligence, physical fitness, aesthetics, and labor. An evaluation that encompasses both comprehensive quality assessment and core literacy assessment is considered to be comprehensive. Core literacy and comprehending quality are complementary and complementary to each other, forming an integrated whole. A student's core literacy refers to the key qualities and abilities that they should possess in order to adapt to their lifelong development and the needs of society. In particular, it includes three aspects: cultural foundation, autonomous development, and participation in society. As a result, an individual's comprehensive quality exhibits the characteristics of wholeness, long-term nature, and stability, which determine the person's behavior in a variety of settings[2]. In December 2014, the ministry of education of China issued the opinions on strengthening and improving the comprehensive quality evaluation of students in regular senior high schools, which defined students' comprehensive quality in five areas, namely, students' ideological and moral character, academic performance, physical and mental health, artistic accomplishment and innovative practice, among others[3]. It is important to consider all of these in developing and evaluating the comprehensive quality of students.

It is common for most traditional educational evaluation methods to use scores as their primary reference standard. This evaluation method often focuses too much on theoretical knowledge and lacks the collection, organization, analysis and evaluation of data in the learning process, which results in a lack of objectivity and fairness in education and makes it difficult to assess students' learning outcomes and development potential. In evaluating students, it is important not only to pay attention to their scores, but also to their specialties and potentials. To cultivate outstanding talents, we should take into account the individuality and needs of students, respect their differences and diversity, combine all-round development with individual development, and integrate various elements of morality, intellect, physical fitness, aesthetics and labor into specific educational evaluations. In order to transform and upgrade basic education, educational evaluation plays a significant role. Ralph Taylor proposed that evaluating curriculum teaching is an important part of determining whether teaching objectives have been implemented, to what extent, and thereby correcting curriculum teaching activities[4]. The evaluation of students is an important component of educational evaluation. Students' learning situations can be comprehensively understood through student evaluation. In student evaluation, various evaluation methods are used to perform systematic analysis and value judgment on the development processes and changes of students. And their influencing factors, as well as to assess the value added of education based on certain evaluation standards[5]. In the reform of basic education, the comprehensive quality level is the cornerstone for actively adapting to and improving the educational quality. Students' comprehensive quality can be improved by conducting comprehensive quality assessments. The core content of comprehensive quality assessment must be assessed in a scientific, objective and precise manner, identified and resolved current problems that hinder students' comprehensive quality development, as well as providing beneficial guidance. As a result of observing, recording, analyzing and evaluating students' learning activities, comprehensive quality assessment acquires process data regarding the true performance of students' comprehensive qualities, which is the basis for achieving precise assessment. As artificial intelligence advances, a comprehensive quality evaluation of students requires data in multiple fields and formats. The data come from a variety of sources, such as schools, families, communities and science and technology museums. Both inside and outside the education system are involved in the data ownership process[6]. The process of assessing quality comprehensively is a complex one. It is currently insufficient to collect and analyze process data. There are numerous challenges involved in conducting a comprehensive evaluation of students, including the lack of integrity in the evaluation content, the excessive dispersal, objectivity in the evaluation methods, concern about the authenticity of the evaluation materials, and the effects of evaluation results on students[7]. These constraints have significantly hindered the practical application and effectiveness of comprehensive quality evaluation.

Due to the development of society, the role and influence of decision-making have become increasingly important, and a variety of fields have also developed higher requirements for decision-making. We are no longer able to meet our needs by relying on information derived from a single dimension. The decision-making process will be further improved in terms of efficiency and accuracy. An all-round developed talent with innovative abilities requires a scientific and reasonable quality evaluation system, which is of vital importance in cultivating all-round developed talents. Information plays an important role in the accuracy of decision-making. Making the right decision can be enhanced by having access to rich information. Education, however, involves a number of complex factors. Educators are organized into educational groups that are individualized and diverse, and each group has its own characteristics. The information generated during the educational process is also complex and subject to change, which can lead to cognitive biases when decision-makers make decisions. Furthermore, the channels through which decision-makers collect information for decision-making are also limited, resulting in a large amount of ambiguous or uncertain information in education. Information of this nature will present certain obstacles to the decision-making process in education. Despite the limited and vague information we have at our disposal, we should make scientific and accurate decisions. The digital transformation of education involves complex, multi-dimensional, multi-featured, and multi-objective data. This complexity, characterized by vagueness and subjectivity in assessing non-cognitive skills, necessitates a decision-making tool like intuitionistic fuzzy sets, which can inherently model such uncertainty. This study aims to construct a new intuitionistic fuzzy entropy evaluation model based on reality to make up for the shortcomings of traditional evaluation methods and promote improved student quality.

The evaluation method proposed in this study has the following advantages:

1) It can make up for the deficiencies of traditional evaluation methods. Traditional evaluation is easily influenced by subjective preferences, incomplete information or ambiguous description. However, this method quantifies hesitation and uncertainty through intuitionistic fuzzy entropy, which can more accurately capture the dimensions that are difficult to measure precisely in the evaluation and significantly reduce human bias.

2) In multi-attribute comprehensive evaluation, traditional methods often adopt simple weighting or ignore the associations between attributes. This method conducts multi-attribute decision-making based on intuitionistic fuzzy entropy, which can systematically integrate various attributes and evaluate the information contribution and importance of each attribute with the help of entropy values, thereby achieving a more balanced and scientific comprehensive assessment.

2 Overview of Intuitionistic Fuzzy Entropy

As early as 1965, Zadeh, the renowned American cybernetics expert, proposed the concept of fuzzy sets[8]. As a result, it extends the membership degree in the original set from strict 0 and 1 to any real number between these two numbers in order to accurately describe fuzzy objects. Zadeh's fuzzy set initially used a single membership degree to represent both affirmative and negative attitudes. It is possible, however, for decision makers in a complex and changing social environment to demonstrate hesitation or remain neutral in the actual decision making process. As a result, neutrality has also become an accepted attitude in addition to affirmation and negation. Atanassov extended the theory of fuzzy sets in 1986, defining intuitionistic fuzzy sets for the first time, which describe fuzziness of information through membership degrees, non-membership degrees, and hesitation degrees[9]. In their introduction to intuitionistic fuzzy sets, Szmidt and Kacprzyk introduced the theory of entropy into intuitionistic fuzzy sets and proposed four conditions that intuitionistic fuzzy entropy should satisfy, thus defining a new formula for intuitionistic fuzzy entropy[10]. As a result, many scholars have paid attention to the construction of intuitionistic fuzzy entropy, and they have made improvements on this basis.

Definition 1([11])**.** Let X be a non-empty set of discourses. It is possible to express an intuitionistic fuzzy set A on X as follows

$$A=\{< x_i, \mu_A(x_i), v_A(x_i) > | x_i \in X\}. \tag{1}$$

In this example, $\mu_A(x)$ and $v_A(x)$ represent the membership and non-membership degrees of A, respectively, satisfying the following condition

$$0 \le \mu_A(x)+v_A(x) \le 1, \forall x_i \in X. \tag{2}$$

If X contains only one element, $<\mu_A, v_A>$ is referred to as an intuitionistic fuzzy number or an intuitionistic fuzzy value.

Definition 2([11])**.** Intuitionistic fuzzy number x in X, if $\pi_A(x)=1-\mu_A(x)-v_A(x)$, $x\in X$, then $\pi_A(x)$ represents the hesitancy degree of x belonging to A. It is evident that $0\le\pi_A(x)\le1$, $x\in X$.

Definition 3([11])**.** Let $A=\{<x_i, \mu_A(x_i), v_A(x_i)>|x_i\in X\}$ and $B=\{<x_i, \mu_B(x_i), v_B(x_i)>|x_i\in X\}$ represent two intuitionistic fuzzy sets. According to intuitionistic fuzzy sets, the operational laws are as follows:

1) $A\subseteq B\Leftrightarrow\mu_A(x_i)\le\mu_B(x_i), v_A(x_i)\ge v_B(x_i), \forall x_i\in X$;

2) $A=B\Leftrightarrow A\subseteq B\cap B\subseteq A$;

3) $A^C=\{<x_i, v_A(x_i), \mu_A(x_i)>|x_i \in X\}$.

Definition 4([10]). When a mapping E: IFS(X)→[0, 1] meets the following criteria, it is said to be an intuitionistic fuzzy entropy.

1) E(A)=0 if and only if A is a crisp set;

2) E(A)=1 if and only if $\mu_A(x)=v_A(x)$, $\forall x_i \in X$;

3) $E(A)=E(A^C)$, where $A^C=\{<x_i, v_A(x_i), \mu_A(x_i)>|x_i \in X\}$;

4) For $\forall x_i \in X$, if

$\mu_B(x_i) \le v_B(x_i)$, then $\mu_A(x_i) \le \mu_B(x_i)$, $v_A(x_i) \ge v_B(x_i)$;

$\mu_B(x_i) \ge v_B(x_i)$, then $\mu_A(x_i) \ge \mu_B(x_i)$, $v_A(x_i) \le v_B(x_i)$,

all $E(A) \le E(B)$.

3 Improvement of Intuitionistic Fuzzy Entropy

We propose a new intuitionistic fuzzy entropy formula in this paper. Suppose $X=(x_1, x_2, x_3,..., x_n)$, and $A=\{<x_i, \mu_A(x_i), v_A(x_i)>|x_i \in X\}$ be an intuitionistic fuzzy set.

This function is constructed as follows

$$E(A)=\frac{1}{n}\sum_{i=0}^{n}\frac{4\mu_A(x_i)v_A(x_i)}{(\mu_A(x_i)+v_A(x_i))^2} \tag{3}$$

Equation 3 can be proved correct and rational if it satisfies the four constraints in Definition 4. It is then demonstrated that the entropy proposed in this study satisfies all four constraints in Definition 4.

Proof.

1) In the case of A, $\forall x_i \in X$, $\mu_A(x)=0$, $v_A(x)=1$ or $\mu_A(x)=1$, $v_A(x)=0$ follows that E(A)=0. Conversely, if E(A)=0, $\forall x_i \in X$, we have $\mu_A(x)v_A(x)=0$. Therefore, $\mu_A(x)=0$, $v_A(x)=1$ or $\mu_A(x)=1$, $v_A(x)=0$ for $\forall x_i \in X$, indicating the existence of a crisp set for A. As a result, condition 1 is satisfied.

2) There is a situation in which $\mu_A(x)=v_A(x)$, $\forall x_i \in X$ then E(A)=1. Conversely, if E(A)=1, we obtain $\mu_A(x)=v_A(x)$ for $\forall x_i \in X$. As a result, condition 2 is satisfied.

3) Since $A^C=\{<x_i, v_A(x_i), \mu_A(x_i)>|x_i \in X\}$, we have $E(A^C)=E(A)$. As a result, condition 3 is satisfied.

4) Construct the function

$$f(x,y)=\frac{4xy}{(x+y)^2}, x,y \in (0,1) \tag{4}$$

We obtain the following partial derivatives of f(x, y) based on x and y

$$f_x'(x,y)=\frac{4y(x+y)^2-(2x+2y)4xy}{(x+y)^4}=\frac{4y(y^2-x^2)}{(x+y)^4},$$

$$f_y'(x,y)=\frac{4x(x+y)^2-(2x+2y)4xy}{(x+y)^4}=\frac{4x(x^2-y^2)}{(x+y)^4}$$

When $x \le y$, we have $f_x(x, y) \ge 0$, $f_y(x, y) \le 0$. It indicates that $f(x, y)$ is a monotonically increasing function with respect to x, and decreasing function with respect to y. Therefore, when $\mu_B(x_i) \le v_B(x_i)$ and $\mu_A(x_i) \le \mu_B(x_i)$, $v_A(x_i) \ge v_B(x_i)$, we have $f(\mu_A(x), v_A(x)) \le f(\mu_B(x), v_B(x))$.

Similarly, when $x \ge y$ we have $f_x(x, y) \le 0$, $f_y(x, y) \ge 0$, it indicates that $f(x, y)$ is a monotonically decreasing function with respect to x, and increasing function with respect to y. Therefore, when $\mu_B(x_i) \ge v_B(x_i)$ and $\mu_A(x_i) \ge \mu_B(x_i)$, $v_A(x_i) \le v_B(x_i)$, we have $f(\mu_A(x), v_A(x)) \le f(\mu_B(x), v_B(x))$, thus $E(A) \le E(B)$. As a result, condition 4 is satisfied.

This completes the proof that the proposed entropy formula satisfies all four conditions outlined in Definition 4.

4 Intuitionistic Fuzzy Multi-Attribute Decision-Making Algorithm Based on Improved Fuzzy Entropy

Assume that the alternative set for the multi-criteria decision-making problem is $X=(x_1, x_2, x_3,..., x_n)$, while the criterion set is $C=(c_1, c_2, c_3,..., c_m)$. The attribute value of alternative x_i with respect to criterion c_i provided by the decision maker is recorded as an intuitionistic fuzzy number $x_{ij}=<\mu_{ij}, v_{ij}>(i=1, 2,..., m; j=1, 2,..., n)$, where μ_{ij} and v_{ij} represent the membership degree and non-membership degree, respectively, given by the decision maker when evaluating alternative x_i with respect to criterion c_i, satisfying $\mu_{ij}, v_{ij} \in [0, 1]$ and $0 \le \mu_{ij}+v_{ij} \le 1$. This evaluation study's decision matrix can be calculated as $D=(<\mu_{ij}, v_{ij}>)_{m\times n}$. The weight of criterion c_i is $\omega_j \in [0, 1]$, $\Sigma\omega_j=1$. If the weights of the criterion are unknown, we follow the following steps:

1) Let $D=(x_{ij})$ be the intuitionistic fuzzy decision matrix. Calculate the entropy E_i for each criterion c_i

$$E_{ij}=\frac{4\mu_{ij}v_{ij}}{(\mu_{ij}+v_{ij})^2} \tag{5}$$

2) Determine the weight coefficient e_i for every criterion

$$e_j=-\frac{1}{\ln m}\sum_{i=1}^{m}E_{ij}\ln E_{ij},\ j=1,2,\ldots,n \tag{6}$$

3) Calculate the weights for each criterion

$$\omega_j=\frac{1-e_j}{n-\sum_{j=1}^{n}e_j} \tag{7}$$

TOPSIS is a method used in multi-criteria decision-making to determine the order of preferences based on similarity to the ideal solution. As a result, this paper adopts the TOPSIS approach to evaluation[12]. As a summary, intuitionistic fuzzy set multi-attribute decision-making based on TOPSIS involves the following algorithm.

1) Determine the alternative set $X=(x_1, x_2, x_3,..., x_n)$ and the criterion set $C=(c_1, c_2, c_3,..., c_m)$.

2) Obtain the intuitionistic fuzzy decision matrix $D=(<\mu_{ij}, v_{ij}>)_{m\times n}$ and compute the weights accordingly to obtain the weighted intuitionistic fuzzy decision matrix.

3) Determine the positive ideal solution $X^+ = (<\mu_1^+, v_1^+>,...,<\mu_m^+, v_m^+>)$ and the negative ideal solution $X^- = (<\mu_1^-, v_1^->,...,<\mu_m^-, v_m^->)$,

where $<\mu_m^+, v_m^+> = <1,0>; <\mu_m^-, v_m^-> = <0,1>$.

4) Determine the Hamming distances of each alternative to the positive and negative ideal points

$$d(x_i, x^+) = \frac{1}{2}\sum_{j=1}^{n}\omega_j[|1-\mu_{ij}| + v_{ij} + |1-\mu_{ij}-v_{ij}|] = \frac{1}{2}\sum_{j=1}^{n}2\omega_j(1-\mu_{ij})$$

$$d(x_i, x^-) = \frac{1}{2}\sum_{j=1}^{n}\omega_j[\mu_{ij} + |1-v_{ij}| + |1-\mu_{ij}-v_{ij}|] = \frac{1}{2}\sum_{j=1}^{n}2\omega_j(1-v_{ij})$$

5) Find the relative closeness coefficient A_i for each alternative

$$A_i = \frac{d(x_i, x^+)}{[d(x_i, x^+) + d(x_i, x^-)]}$$

6) Identify the optimal alternative from the set X by examining the magnitude of the relative closeness coefficient A_i.

5 Analyses of Numerical Examples

In this paper, the problem of comprehensive quality evaluation of students is used as a numerical example to examine the effectiveness and practicality of the improved intuitionistic fuzzy entropy decision-making approach. Assume that a school has determined four comprehensive quality cultivation programs $X_i(i=1, 2, 3, 4)$ based on the work experience of teachers and preliminary investigations in order to improve students' holistic qualities and promote their all round development. School evaluation criteria include moral character c_1, academic performance c_2, physical and mental health c_3, artistic literacy c_4, and innovative practice c_5. Experts are invited to score each program under each criterion c_i, resulting in satisfaction μ_{ij} and dissatisfaction v_{ij} ratings pertaining to program X_i.

Assume that the evaluation information for the programs $X_i(i=1, 2, 3, 4)$ under the criteria $C_i(i=1, 2, 3, 4, 5)$ is expressed using intuitionistic fuzzy sets, and Table 1 shows the corresponding intuitionistic fuzzy decision matrix $D=(<\mu_{ij}, v_{ij}>)_{m\times n}$.

To compare and rank the alternative comprehensive quality cultivation plans, the following section will use the decision making method presented in this paper.

Table 1. Intuitionistic fuzzy decision information table for comprehensive quality cultivation program evaluation[13].

	C_1	C_2	C_3	C_4	C_5
X_1	0.72, 0.23	0.75, 0.15	0.75, 0.15	0.78, 0.16	0.72, 0.15
X_2	0.63, 0.32	0.74, 0.21	0.78, 0.15	0.74, 0.18	0.77, 0.17
X_3	0.65, 0.25	0.74, 0.12	0.78, 0.15	0.75, 0.16	0.76, 0.14
X_4	0.75, 0.15	0.75, 0.15	0.72, 0.15	0.78, 0.15	0.73, 0.12

1) Constructing the intuitionistic fuzzy decision matrix

$$D = \begin{bmatrix} <0.72,0.23> & <0.75,0.15> & <0.75,0.15> & <0.78,0.16> & <0.72,0.15> \\ <0.63,0.32> & <0.74,0.21> & <0.78,0.15> & <0.74,0.18> & <0.77,0.17> \\ <0.65,0.25> & <0.74,0.12> & <0.78,0.15> & <0.75,0.16> & <0.76,0.14> \\ <0.75,0.15> & <0.75,0.15> & <0.72,0.15> & <0.78,0.15> & <0.73,0.12> \end{bmatrix}$$

2) Calculate the intuitionistic fuzzy entropy using equation 3. The results are shown in Table 2.

Table 2. Computation results of intuitionistic fuzzy entropy.

E	C_1	C_2	C_3	C_4	C_5
X_1	1.159	0.769	0.769	0.787	0.799
X_2	1.615	1.051	0.742	0.919	0.842
X_3	1.34	0.632	0.742	0.816	0.713
X_4	0.769	0.769	0.799	0.742	0.640

Based on the steps described above, the criterion weight vector is $\omega = (0.495, 0.146, 0.110, 0.144, 0.105)$.

3) Calculate and obtain positive ideal solution

$$X^{+} = (<0.75,0.32><0.75,0.21><0.78,0.15><0.78,0.18><0.77,0.17>)$$

and negative ideal solution

$$X^{-} = (<0.63,0.15><0.74,0.12><0.72,0.15><0.74,0.15><0.72,0.12>)$$

4) Determine the Hamming distances between each alternative X_i and the positive and negative ideal points

$$d(x_1,x^{+})=0.264, d(x_2,x^{+})=0.257, d(x_3,x^{+})=0.297, d(x_4,x^{+})=0.251$$

$$d(x_1 x^{-})=0.809, d(x_2,x^{-})=0.751, d(x_3,x^{-})=0.804, d(x_4,x^{-})=0.853$$

5) Find the relative closeness coefficient A_i for the i alternative

$$A_1 = 0.246, A_2 = 0.255, A_3 = 0.270, A_4 = 0.227.$$

6) Rank the alternatives based on the values of A_i. Based on the comprehensive quality cultivation plans, the ranking result is as follows: $X_3 > X_2 > X_1 > X_4$, where X_3 is the optimal cultivation plan.

Based on the expert scores and the evaluation results output by the model, this process can inspire us and form the following suggestions in teaching and learning. For teachers, it is recommended that they take the initiative to learn and master new evaluation methods, especially those involving intuitionistic fuzzy numbers and other forms. Teachers should be familiar with the corresponding modeling methods or related software tools to enhance the scientificity and accuracy of the evaluation. For students, the cultivation of comprehensive qualities is a vital importance to their long term development. Students should actively participate in various practical activities, exercise their abilities in real situations, and thereby enhance their comprehensive quality.

6 Conclusion

According to this study, based on an analysis of the existing literature on intuitionistic fuzzy entropy, an improved intuitionistic fuzzy entropy formula is developed based on the predicaments faced by students in comprehensive quality evaluation and the multidimensional characteristics of comprehensive quality evaluation. By using this method, we can better denote the fuzziness and uncertainty of intuitionistic fuzzy sets, and we will also be able to enrich the attribute weight method and the intuitionistic fuzzy decision-making method based on entropy. It is possible to quickly rank the advantages and disadvantages of the comprehensive quality cultivation program through the analysis of the evaluation case when there are multiple indicators included in the evaluation, improving the efficiency of the decision-making process by applying this method when there are multiple indicators involved. These findings add to the comprehensive quality evaluation system by providing theoretical support and practical guidance for cultivating and enhancing the comprehensive quality of students at elementary and secondary schools.

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