# Teaching Quality Evaluation of Engineering Cost Courses Based on Fuzzy Analytic Hierarchy Process

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**Abstract—**The prosperous economic development and the investment and construction of several construction projects have substantially promoted the demands for talents in the engineering cost specialty. Nowadays the engineering cost specialty programs in many universities are faced with the strong applicability problem of specialized courses, and the teaching design for such specialized courses fails to meet the demands of the construction industry that enjoys high-speed development. A novel method to accurately evaluate the professional courses on the basis of the fuzzy analytic hierarchy process (FAHP) was proposed in this study. The weights of course evaluation indexes were determined by the FAHP, thus realizing the quantitative evaluation of course teaching quality. This study combined the teaching reform practice in analyzing the special characteristics of the engineering cost course. Based on the theory of outcomes-based education and multiple evaluation approaches, it established a closed-loop model for the progressive development of teaching management and expounded the evolutionary process and driving pattern of course teaching evaluation. Results demonstrate that an evaluation index system consisting of 22 evaluation indexes in 5 dimensions is suitable for the course, the teaching quality ratings can be quantified by this method, such as 81.43 points, and they can provide a certain reference for the course construction and teaching quality evaluation of this specialty. The proposed method provides a good prospect to optimize the teaching quality evaluation in the professional curriculums.

**Keywords—**teaching evaluation, outcomes-based education, multiple evaluation approaches, fuzzy analytic hierarchy process, dynamic development model of teaching evaluation

## 1 Introduction

The construction industry has proposed increasing demands for highly skilled talents owing to the rapid economic development and the updating of the industrial structure. However, the present higher education system values academic learning while neglecting application-oriented talents, leading to a mismatch between teaching and job role [1]. Under the Washington Agreement, all member States enjoy mutual recognition of international degrees in engineering education. Especially for the training of engineering talents in domestic applied universities, colleges and universities should shift to the training of application-oriented skilled talents, and the professional construction should be oriented toward the engineering education certification standards led by the Ministry of Education.

In recent years, more and more specialties in colleges and universities have established demand-oriented cultivation standards such as dislocation development, industry-teaching integration, and collaborative talent cultivation to nurture high-quality industrial talents with a high sense of social responsibility, professional literacy, strong practical abilities, and innovation and entrepreneurial abilities. During the formation of new standards, colleges and universities will be faced with the following problem: how to cultivate application-oriented and highly skilled talents to meet the local industrial development needs. Therefore, a pertinent evaluation mechanism is required to evaluate the teaching quality of professional courses. The course teaching quality evaluation is an important constituent part of engineering education certification, but evaluation indexes are problematic regarding scientificity, objectivity, and effectiveness in teaching management [2]. Most of the present teaching quality evaluation models are relatively direct without considering the differences between ordinary optional courses and professional courses, not to mention the differences in disciplines and student background. Most evaluation results are only applied to performance allocation, but the evaluation goal of teaching promotion is not considered. By contrast, an efficient professional course teaching quality evaluation system is conducive to promoting the teaching quality and practical teaching of graduates from engineering specialties and further enhancing their comprehensive practical skills and abilities.

## 2 State of the art

Many universities both domestic and overseas have explored and investigated the course system, teaching contents, teaching methods, and teaching strategies of professional technical courses. As for index system construction, Marwan et al. [3] established an index system for professional management ability elements through an expert group's web-based learning research program. To solve uncertainties of evaluation index systems and information acquisition through the AHP method, Fernando et al. [4] put forward the IC-FSAHP method that further expanded the model self-adaptability through random simulation. Chinese scholars Diao Y B et al. [5] established an experiential-type entrepreneurship teaching evaluation index system based on the CIPP model to improve the entrepreneurship teaching quality. Considering such factors as technicality, heterogeneity, interactivity, orientation, predictability, and growth, Zheng Q et al. [6] constructed a practical teaching evaluation index system for application-oriented universities based on constructivism theory from four dimensions: teaching process, teaching staffing, classroom environment, and quality control. With teachers, students, and supervisors as the evaluation subjects, Qiu W J et al. [7] established an inquiry-type classroom teaching index system framework based on a full consideration of the "student-oriented" developmental teaching quality evaluation system.

In terms of teaching quality evaluation, foreign scholar Swacha [8] investigated the internal structural relations between indexes using the multivariate statistics method and built a structured classroom teaching quality evaluation index system model. Wolnowska et al. [9] compared three path variables through AHP and selected the optimal scheme to provide reasonable method solving complex systems. Borovička [10] constructed a trigonometric fuzzy function representation to realize the preference importance of expressions and then establish the decision criteria for a set of alternatives evaluated by different important factors, which is a systematic theoretical decision method. Nirmala et al. [11] constructed a flipped classroom teaching evaluation system and a comprehensive evaluation method by virtue of AHP. Based on experts' knowledge and experience, Balsara et al. [12] used the Delphi group decision to construct a teaching quality evaluation index framework. Chinese scholars Zhao X R et al. [13] used the FAHP method to construct an MOOC teaching quality evaluation index system and applied it to the empirical research. Cui M et al. [14] simulated expert thoughts by improving the BP neural network algorithm to evaluate innovation and entrepreneurship teaching abilities of college teachers. Cai Z H et al. [15] established a two-stage teaching evaluation model from the perspective of teachers and gave weight proportional factors. Xu W W et al. [16] determined a teaching evaluation index system and index weights considering the integrality, orientation, and intuition principles of teaching evaluation. Guo J et al. [17] adopted the AHP method to explore the degree-level evaluation theory for master pilots of international education of Chinese language.

Most of the related studies have focused on large-scale teaching evaluation from the perspective of teaching administration departments. Some scholars have also investigated the evaluation index system for teachers' abilities, practical teaching, and innovation and entrepreneurship teaching, but nearly no fine teaching evaluation specific to professional courses exists. Given this scenario, the exclusive characteristics of engineering cost courses in regionalism, timeliness, practicability, and normalization were analyzed in this research based on outcomes-based education (OBE) concept and multiple evaluation theory. Next, a dynamic development model of professional course teaching quality evaluation was proposed. A trigonometric fuzzy function was also introduced using the fuzzy analytic hierarchy process (FAHP), and upper and lower limits were used to judge the possible range or compare the strength for quantitative depiction. Then, a teaching quality evaluation model for *Construction Engineering Measurement and Valuation* (CEMV) was established to quantitatively analyze the evaluation objects. Subsequently, a systematic evaluation was performed from five dimensions: teaching preparation, teaching method, teaching process, teaching output, and teaching effect. In addition, the evaluation criteria and the weight of each influencing factor were quantified to obtain the quantitative score of course teaching quality and determine the teaching evaluation grade. Finally, the course design and teaching practice are guided according to the importance level of relevant factors.

## 3 Methodology

The weights of teaching evaluation indexes are determined through the Delphi method, factor analysis method, AHP method, CIPP pattern, BP neural network, and FAHP. In literature [18], the advantages and disadvantages of teaching evaluation methods were thoroughly analyzed, and the features of evaluation objects and organization conditions were thought to require comprehensive consideration in the method selection. After systematic evaluation and selection, the FAHP method was used in this research to calculate the weight of each evaluation index. The basic idea and steps of this method coincided with those of the AHP method proposed by Saaty et al.

### 3.1 Selection of evaluation indexes

With the CEMV as the research object, its teaching quality evaluation index system was constructed on the basis of the theory of outcomes-based education and multiple evaluation considering regionalism, timeliness, practicality, and normalization. This system was also applicable to companion courses, *Installation Engineering Measurement and Valuation* (IEMV), and *Municipal Engineering Measurement and Valuation* (MEMV).

The test was performed using a five-point Likert's scale, namely, "disagree very much," "disagree," "ordinary," "agree," and "agree very much." Three application-oriented universities establishing the engineering cost specialty, namely, Beibu Gulf University, Guangxi University of Finance and Economics, and Anhui University of Science and Technology, were selected for the questionnaire survey. A total of 860 questionnaires were distributed, among which 727 ones were returned. After excluding invalid questionnaires, 645 valid ones were obtained, with a recovery rate of 84.5% and an effective rate of 88.7%. Through demonstration of the expert group, a course evaluation index system containing 5 first-level indexes and 22 second-level indexes was determined.

### 3.2 Allocation of index weights

**Construction of evaluation model.** With the professional course teaching of CEMV as the evaluation object, this system was divided into the following four layers: target layer, criterion layer, index layer, and scheme layer. Then, a course teaching quality evaluation model was established as shown in Figure 1.

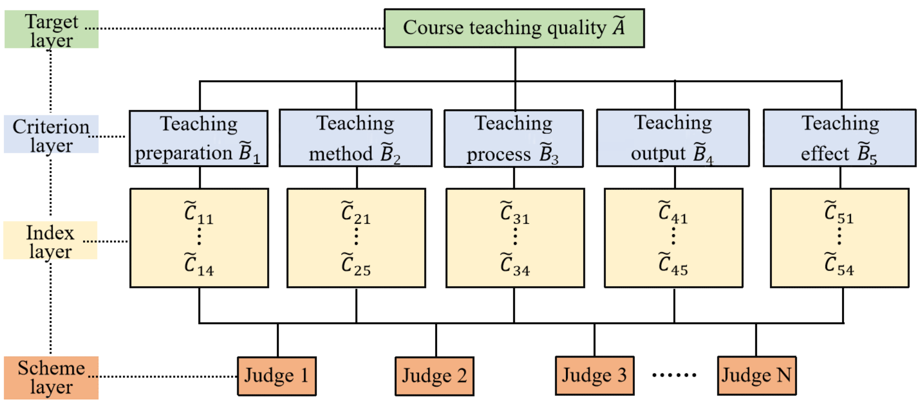


**Fig. 1.** Course teaching quality evaluation model

**Fuzzy function.** If the function $\mu(x)$: $R \rightarrow [0,1]$ of the fuzzy set $M$ is within the domain $R$, $\mu(x)$ can be given as [19].

$$\mu(x)=\begin{cases}\frac{x-l}{m-l} & x\in[l,m]\\ \frac{x-u}{m-u} & x\in[m,u],\\ 0 & \text{otherwise}\end{cases} \tag{1}$$

where $l \leq m$ and $l \leq u$. Therein, $l$ and $u$ indicate the lower and upper bounds of $M$, respectively, denoting the degree of fuzziness: the greater the $u - l$, the higher the fuzzy degree. $m$ is the value when the membership of the fuzzy set $M$ is 1. Therefore, this trigonometric fuzzy function is introduced to improve the judgment scale (1–9) of AHP [20] and establish the corresponding fuzzy scale as shown in Figure 2.

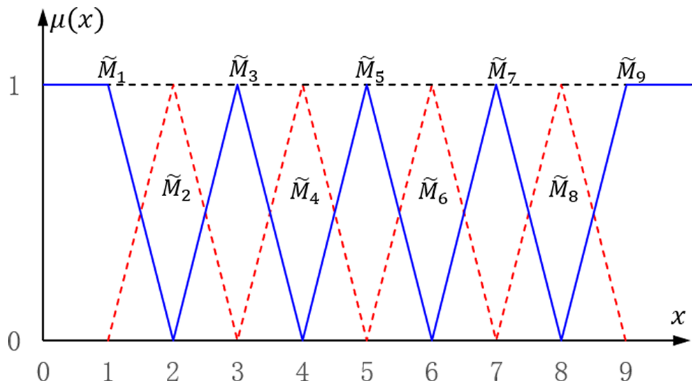


**Fig. 2.** Geometric distribution of fuzzy scale

**Weight determination.** When it comes to decision making over a complex problem, the research object should be divided into several layers, and a fuzzy judgment matrix is constructed using the FAHP method, followed by defuzzification, consistency check, and normalization, to realize collective and scientific decision making of experts and obtain evaluated weights. This process is concluded into the following steps:

Step 1: As shown in Figure 2, a $K$-layer course hierarchy model is established, and $K = 4$ in this case.

Step 2: A fuzzy comparison matrix $\tilde{A}=[\tilde{a}_{ij}]$ is constructed using the trigonometric fuzzy set $M$.

Step 3: The geometric mean $\tilde{r}_i^k$ of the column vectors for the index $i$ at the layer $K$ calculated through the following equation:

$$\tilde{r}_i^k=\left(\prod_{j=1}^{n}\tilde{a}_{ij}^k\right)^{\frac{1}{n}} \tag{2}$$

In Equation (2),

$$\prod_{j=1}^{n} \tilde{a}_{ij}^{k} = \left( \prod_{j=1}^{n} l_{ij}^{k}, \prod_{j=1}^{n} m_{ij}^{k}, \prod_{j=1}^{n} u_{ij}^{k} \right) \tag{3}$$

Step 4: The initial weight $\tilde{w}_i$ is calculated through Equations (4) and (5):

$$\tilde{w}_i = \tilde{r}_i^2 \odot \left( \sum_{i=1}^{n} \tilde{r}_i^2 \right)^{-1} \tag{4}$$

$$W' = [\tilde{w}_1, \tilde{w}_2, \ldots\ldots \tilde{w}_n]^{\mathrm{T}} \tag{5}$$

Step 5: Weight defuzzification is implemented using the Center of Area (COA) method [20].

$$\tilde{w}_i = \frac{l_i + w_i + u_i}{3}. \tag{6}$$

Step 6: Index weights are normalized as below:

$$W = [d(\tilde{A}_1), d(\tilde{A}_2), \cdots\cdots, d(\tilde{A}_n)]^{\mathrm{T}} \tag{7}$$

$$d(\tilde{A}_i) = \tilde{w}_i \odot \left( \sum_{i=1}^{n} \tilde{w}_i \right)^{-1} \tag{8}$$

Step 7: Steps 3–6 are repeated to determine the weight of each index, and the total index weight $W_i^t$ at the objective layer is solved as per Equation (9).

$$W_i^t = d(\tilde{A}_i) \odot W_i. \tag{9}$$

Step 8: An evaluation set $V$ is constructed according to the comment set of the evaluation object:

$$V = (V_1, V_2, \cdots\cdots, V_m). \tag{10}$$

Step 9: Single-factor fuzzy evaluation is carried out to obtain a single-factor evaluation matrix:

$$R_i = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}, 0 \le r_{ij} \le 1. \tag{11}$$

Step 10: The comprehensive evaluation vector $B_i$ of each subobjective is calculated as follows:

$$B_i = W_i R_i (i = 1, 2, \cdots\cdots, k), \tag{12}$$

$$B_i = (B_1, B_2, \cdots\cdots, B_k)^T. \tag{13}$$

Step 11: The evaluation vector of the general objective is calculated through Equation (14) to obtain the maximum membership and the teaching evaluation level.

$$C = AB. \tag{14}$$

**Fuzzy comment evaluation system is constructed.** A comment set is formed through experts' teaching comments consisting of 22 single factors at the index layer of the hierarchical course teaching evaluation model. Scores are calculated using Likert scale; the comments with approximate conceptual meanings are scored using the degree of recognition; and actual comments are classified into 5 classes: excellent, good, qualified, poor, and very poor. As seen in Table 1, comments P1, P2, P3, P4, and P5 are subjective comments given by the assessment group, which are defined by the centesimal "evaluation standard Q" as "excellent, good, qualified, poor, and very poor" to form a comment set and construct the V = {9,7,5,3,1} set.

**Table 1.** Fuzzy evaluation criteria

| Subjective Comments | Fuzzy Evaluation | | Evaluation Standard | Score |
|---|---|---|---|---|
| | Comment Grade $\tilde{V}$ | Evaluation Standard $Q$ | | |
| Comment *P1* | (9, 9, 9) | $x > 8$ | excellent (9) | 90 |
| Comment *P2* | (6, 7, 8) | $6 < x \leq 8$ | good (7) | 75 |
| Comment *P3* | (4, 5, 6) | $4 < x \leq 6$ | qualified (5) | 60 |
| Comment *P4* | (2, 3, 4) | $2 < x \leq 4$ | poor (3) | 45 |
| Comment P5 | (1, 1, 1) | $x \leq 2$ | very poor (1) | 30 |

# 4 Result analysis and discussion

## 4.1 Establishment of evaluation model

According to the course features of CEMV, a hierarchical teaching quality evaluation model was constructed as shown in Figure 1. The comparative scales were quantitatively depicted using a trigonometric fuzzy function. A teaching evaluation group was organized to compare every two factors and assign values to them, thus obtaining the following judgment matrix:

$$\tilde{A}=\begin{bmatrix} (1,1,1) & (4,5,6) & (1,2,3) & (\tfrac{1}{3},\tfrac{1}{2},1) & (\tfrac{1}{3},\tfrac{1}{2},1) \\ (\tfrac{1}{6},\tfrac{1}{5},\tfrac{1}{4}) & (1,1,1) & (\tfrac{1}{4},\tfrac{1}{3},\tfrac{1}{2}) & (\tfrac{1}{8},\tfrac{1}{7},\tfrac{1}{6}) & (\tfrac{1}{9},\tfrac{1}{9},\tfrac{1}{9}) \\ (\tfrac{1}{3},\tfrac{1}{2},1) & (2,3,4) & (1,1,1) & (\tfrac{1}{3},\tfrac{1}{2},1) & (\tfrac{1}{4},\tfrac{1}{3},\tfrac{1}{2}) \\ (1,2,3) & (6,7,8) & (1,2,3) & (1,1,1) & (\tfrac{1}{3},\tfrac{1}{2},1) \\ (1,2,3) & (9,9,9) & (2,3,4) & (1,2,3) & (1,1,1) \end{bmatrix}$$

$$\tilde{B}_1=\begin{bmatrix} (1,1,1) & (\tfrac{1}{4},\tfrac{1}{3},\tfrac{1}{2}) & (\tfrac{1}{3},\tfrac{1}{2},1) & (1,2,3) \\ (2,3,4) & (1,1,1) & (1,2,3) & (4,5,6) \\ (1,2,3) & (\tfrac{1}{3},\tfrac{1}{2},1) & (1,1,1) & (2,3,4) \\ (\tfrac{1}{3},\tfrac{1}{2},1) & (\tfrac{1}{6},\tfrac{1}{5},\tfrac{1}{4}) & (\tfrac{1}{4},\tfrac{1}{3},\tfrac{1}{2}) & (1,1,1) \end{bmatrix}$$

$$\tilde{B}_2=\begin{bmatrix} (1,1,1) & (\tfrac{1}{3},\tfrac{1}{2},1) & (\tfrac{1}{3},\tfrac{1}{2},1) & (1,2,3) & (\tfrac{1}{4},\tfrac{1}{3},\tfrac{1}{2}) \\ (1,2,3) & (1,1,1) & (1,2,3) & (3,4,5) & (\tfrac{1}{3},\tfrac{1}{2},1) \\ (1,2,3) & (\tfrac{1}{3},\tfrac{1}{2},1) & (1,1,1) & (2,3,4) & (\tfrac{1}{3},\tfrac{1}{2},1) \\ (\tfrac{1}{3},\tfrac{1}{2},1) & (\tfrac{1}{5},\tfrac{1}{4},\tfrac{1}{3}) & (\tfrac{1}{4},\tfrac{1}{3},\tfrac{1}{2}) & (1,1,1) & (\tfrac{1}{6},\tfrac{1}{5},\tfrac{1}{4}) \\ (2,3,4) & (1,2,3) & (1,2,3) & (4,5,6) & (1,1,1) \end{bmatrix}$$

$$\tilde{B}_3=\begin{bmatrix} (1,1,1) & (\tfrac{1}{3},\tfrac{1}{2},1) & (3,4,5) & (1,2,3) \\ (1,2,3) & (1,1,1) & (4,5,6) & (1,2,3) \\ (\tfrac{1}{5},\tfrac{1}{4},\tfrac{1}{3}) & (\tfrac{1}{6},\tfrac{1}{5},\tfrac{1}{4}) & (1,1,1) & (\tfrac{1}{3},\tfrac{1}{2},1) \\ (\tfrac{1}{3},\tfrac{1}{2},1) & (\tfrac{1}{3},\tfrac{1}{2},1) & (1,2,3) & (1,1,1) \end{bmatrix}$$

$$\tilde{B}_4=\begin{bmatrix} (1,1,1) & (1,2,3) & (2,3,4) & (6,7,8) & (3,4,5) \\ (\tfrac{1}{3},\tfrac{1}{2},1) & (1,1,1) & (1,2,3) & (4,5,6) & (2,3,4) \\ (\tfrac{1}{4},\tfrac{1}{3},\tfrac{1}{2}) & (\tfrac{1}{3},\tfrac{1}{2},1) & (1,1,1) & (2,3,4) & (1,2,3) \\ (\tfrac{1}{8},\tfrac{1}{7},\tfrac{1}{6}) & (\tfrac{1}{6},\tfrac{1}{5},\tfrac{1}{4}) & (\tfrac{1}{4},\tfrac{1}{3},\tfrac{1}{2}) & (1,1,1) & (\tfrac{1}{3},\tfrac{1}{2},\tfrac{1}{1}) \\ (\tfrac{1}{5},\tfrac{1}{4},\tfrac{1}{3}) & (\tfrac{1}{4},\tfrac{1}{3},\tfrac{1}{2}) & (\tfrac{1}{3},\tfrac{1}{2},1) & (1,2,3) & (1,1,1) \end{bmatrix}$$

$$\tilde{B}_5=\begin{bmatrix} (1,1,1) & (2,3,4) & (\tfrac{1}{4},\tfrac{1}{3},\tfrac{1}{2}) & (\tfrac{1}{3},\tfrac{1}{2},1) \\ (1,2,3) & (1,1,1) & (\tfrac{1}{8},\tfrac{1}{7},\tfrac{1}{6}) & (\tfrac{1}{6},\tfrac{1}{5},\tfrac{1}{4}) \\ (2,3,4) & (6,7,8) & (1,1,1) & (1,2,3) \\ (1,2,3) & (4,5,6) & (\tfrac{1}{3},\tfrac{1}{2},1) & (1,1,1) \end{bmatrix}$$

### 4.2 Determination of evaluation index weights

According to the FAHP method, the detailed calculation process is as follows:

When $K$ = 4, the fuzzy comparison matrix $\tilde{A}=[\tilde{a}_{ij}]$ is taken as example, the row vector $\tilde{r}_i^k$ of the matrix $\tilde{A}$ is calculated as per Equation (2) in Step 3:

$$\tilde{r}_1^2 = \left( \sqrt[5]{1\times 4\times 1\times \frac{1}{3}\times \frac{1}{3}}, \sqrt[5]{1\times 5\times 2\times \frac{1}{2}\times \frac{1}{2}}, \sqrt[5]{1\times 6\times 3\times 1\times 1} \right) = (0.850, 1.201, 1.783).$$

Similarly,

$\tilde{r}_2^2 = (0.225, 0.254, 0.297)$, $\tilde{r}_3^2 = (0.561, 0.758, 1.149)$, $\tilde{r}_4^2 = (1.149, 1.695, 2.352)$, $\tilde{r}_5^2 = (1.783, 2.551, 3.178)$.

Step 4: The initial weight $\tilde{w}_i$ is calculated as follows:

$$\sum_{i=1}^{5} \tilde{r}_i^2 = (0.850 + 0.225 + 0.561 + 1.149 + 1.783,\ 1.201 + 0.254 + 0.758 + 1.695 + 2.551,$$
$$1.783 + 0.297 + 1.149 + 2.352 + 3.178) = (4.568, 6.459, 8.758),$$

$$\tilde{w}_1 = (0.850, 1.201, 1.783) \odot (\frac{1}{0.8758}, \frac{1}{6.459}, \frac{1}{4.568}) = (0.097, 0.186, 0.390).$$

Similarly,

$\tilde{w}_2 = (0.026, 0.039, 0.065)$, $\tilde{w}_3 = (0.064, 0.117, 0.251)$, $\tilde{w}_4 = (0.131, 0.262, 0.515)$, $\tilde{w}_5 = (0.204, 0.395, 0.696)$.

Step 5: Defuzzification is performed using Equation (5):

$$\tilde{w}_1 = \frac{0.097 + 0.186 + 0.390}{3} = 0.224,\ \tilde{w}_2 = \frac{0.026 + 0.039 + 0.065}{3} = 0.043,$$
$$\tilde{w}_3 = \frac{0.064 + 0.117 + 0.251}{3} = 0.144,\ \tilde{w}_4 = \frac{0.131 + 0.262 + 0.515}{3} = 0.303,$$
$$\tilde{w}_5 = \frac{0.204 + 0.395 + 0.696}{3} = 0.431.$$

Step 6: Weights are normalized to obtain

$W_A = (0.196, 0.038, 0.126, 0.264, 0.376)^T$,

Step 7: Steps 3–6 are repeated to calculate the weight of each index at other layers.

$W_{B1} = (0.164, 0.465, 0.279, 0.092)^T$, $W_{B2} = (0.125, 0.255, 0.191, 0.066, 0.363)^T$,

$W_{B3} = (0.300, 0.425, 0.085, 0.190)^T$, $W_{B4} = (0.196, 0.038, 0.126, 0.264, 0.376)^T$,

$W_{B5} = (0.416, 0.270, 0.161, 0.055, 0.098)^T$.

The total weight of the target layer is calculated through Equation (9), with results summarized in Table 2.

**Table 2.** Index weights of the course evaluation index system

| Criterion | Weight | Index Layer | Weight | Total Weight |
|---|---|---|---|---|
| Teaching preparation $\tilde{B}_1$ | 0.196 | Reasonable design with full preparation $\tilde{C}_{11}$ | 0.164 | 0.032 |
| | | Knowledge focused with clear emphasis $\tilde{C}_{12}$ | 0.465 | 0.091 |
| | | Theory with practice highlighted $\tilde{C}_{13}$ | 0.279 | 0.055 |
| | | Closely followed the subject frontier $\tilde{C}_{14}$ | 0.092 | 0.018 |
| Teaching method $\tilde{B}_2$ | 0.038 | Flexible teaching methods and practical means $\tilde{C}_{21}$ | 0.125 | 0.005 |
| | | Inspiring thinking, problem oriented $\tilde{C}_{22}$ | 0.255 | 0.010 |
| | | Encouraging innovation and exploration, interest driven $\tilde{C}_{23}$ | 0.191 | 0.007 |
| | | Focus on individual development and aptitude $\tilde{C}_{24}$ | 0.066 | 0.003 |
| | | Engineering case study, highlighted practical operation $\tilde{C}_{25}$ | 0.363 | 0.014 |
| Teaching process $\tilde{B}_3$ | 0.126 | Teaching plan clear and systematic $\tilde{C}_{31}$ | 0.300 | 0.038 |
| | | Class is well organized with interaction $\tilde{C}_{32}$ | 0.425 | 0.054 |
| | | Blackboard writing is complete and neat $\tilde{C}_{33}$ | 0.085 | 0.011 |
| | | Being proactive in learning and teaching $\tilde{C}_{34}$ | 0.190 | 0.024 |
| Teaching output $\tilde{B}_4$ | 0.264 | Teaching practice output, result-oriented $\tilde{C}_{41}$ | 0.416 | 0.110 |
| | | Award winning in competitions and skill improvement $\tilde{C}_{42}$ | 0.270 | 0.071 |
| | | The fusion of industry and education $\tilde{C}_{43}$ | 0.161 | 0.043 |
| | | Innovative research on experiment, science and technology transformation $\tilde{C}_{44}$ | 0.055 | 0.015 |
| | | Social services and extended skills $\tilde{C}_{45}$ | 0.098 | 0.026 |
| Teaching effect $\tilde{B}_5$ | 0.376 | Attendance rate and timing $\tilde{C}_{51}$ | 0.170 | 0.064 |
| | | Test score distribution and combination of test and evaluation $\tilde{C}_{52}$ | 0.060 | 0.023 |
| | | Course objective achievement, success in both teaching and learning $\tilde{C}_{53}$ | 0.475 | 0.179 |
| | | Ability cultivation, learning to use $\tilde{C}_{54}$ | 0.295 | 0.111 |

Step 8: A comment set $V$ = (excellent, good, qualified, poor, very poor) of course teaching quality is constructed.

Step 9: The comments are analyzed from the evaluation experts, and a score is generated with the Likert scale. Comments with similar conceptual meanings will be combined and classified to form a single-factor fuzzy score of five levels. The matrices of each index such as teaching preparation $R_1$, teaching method $R_2$, teaching process $R_3$, teaching output $R_4$, and teaching effect $R_5$ are given as follows:

$$R_1 = \begin{bmatrix} 0.40 & 0.50 & 0.10 & 0.00 & 0.00 \\ 0.50 & 0.30 & 0.20 & 0.00 & 0.00 \\ 0.40 & 0.50 & 0.07 & 0.03 & 0.00 \\ 0.45 & 0.45 & 0.10 & 0.00 & 0.00 \end{bmatrix} \quad R_2 = \begin{bmatrix} 0.40 & 0.45 & 0.10 & 0.05 & 0.00 \\ 0.30 & 0.60 & 0.10 & 0.00 & 0.00 \\ 0.30 & 0.30 & 0.30 & 0.05 & 0.05 \\ 0.50 & 0.40 & 0.10 & 0.00 & 0.00 \\ 0.40 & 0.45 & 0.15 & 0.00 & 0.00 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.40 & 0.35 & 0.15 & 0.10 & 0.00 \\ 0.50 & 0.40 & 0.10 & 0.00 & 0.00 \\ 0.50 & 0.40 & 0.10 & 0.00 & 0.00 \\ 0.55 & 0.35 & 0.05 & 0.05 & 0.00 \end{bmatrix} \quad R_4 = \begin{bmatrix} 0.60 & 0.35 & 0.05 & 0.00 & 0.00 \\ 0.35 & 0.46 & 0.13 & 0.05 & 0.01 \\ 0.55 & 0.40 & 0.05 & 0.05 & 0.05 \\ 0.50 & 0.40 & 0.10 & 0.00 & 0.00 \\ 0.60 & 0.30 & 0.10 & 0.00 & 0.00 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0.70 & 0.25 & 0.05 & 0.00 & 0.00 \\ 0.60 & 0.30 & 0.10 & 0.00 & 0.00 \\ 0.65 & 0.30 & 0.05 & 0.00 & 0.00 \\ 0.60 & 0.35 & 0.05 & 0.00 & 0.00 \end{bmatrix}.$$

Step 10: The comprehensive evaluation vector $B$ of each subobjective is calculated as per Equations (12) and (13):

$$B = (B_1, B_2, \cdots, B_k)^T = \begin{bmatrix} 0.451 & 0.402 & 0.138 & 0.008 & 0.000 \\ 0.362 & 0.456 & 0.156 & 0.016 & 0.010 \\ 0.480 & 0.375 & 0.105 & 0.040 & 0.000 \\ 0.519 & 0.386 & 0.079 & 0.013 & 0.003 \\ 0.641 & 0.306 & 0.053 & 0.000 & 0.000 \end{bmatrix}.$$

Step 11: The vector $C$ of total objective is calculated through Equation (14) to obtain the maximum membership and the teaching quality evaluation grade.

$C = W_A B = (0.541, 0.360, 0.087, 0.011, 0.001)$.

As judged according to the maximum membership, the teaching evaluation grade is "good." On the basis of the hundred-mark system, the total score of the system can be obtained as below such that

$D = 90 \times 0.541 + 75 \times 0.360 + 60 \times 0.087 + 45 \times 0.011 + 30 \times 0.001 = 81.43(\textit{points})$.

### 4.3 Course features after reform

**Regionalism.** As the project cost is closely related to the local laws and regulations, local characteristics of engineering costs and local industrial standards must be considered in the course design. Hence, the selection of teaching materials and course design should consider the practice specified in nationwide (China) general standards and normative and model texts as well as the rules and regulations formulated by local governments and the local specific conventional practice. The course covers the main local laws and regulations of Guangxi, China, on measurement and valuation rules. Course cases and practical operation scenes are designed under the background of engineering costs for local construction projects. Meanwhile, the follow-up industry-teaching integrated internship and substituted post exercitation should be seamlessly docked so that graduates can be blended into the economic construction engineering cost industry in the Beibu Gulf area and to better serve the local economic construction.

**Timeliness.** The codes and standards of the industries involved in the CEMV course are usually dynamically updated every 3–5 years. In particular, policy-type degrees and regulations are continuously adjusted, and course knowledge and rules need continuous updating to synchronously cater to the regional market requirements. Personnel training programs and teaching programs are revised within a certain period, requiring teaching materials and textbooks to be selected with consideration of both continuity and timeliness, which is a challenge for both course design and teachers' abilities. In general, tutors should keep close attention to the policy changes in the local industrial fields. Moreover, they can subtly perceive industrial market changes only by being occupied in consultation services in the engineering cost market.

**Practicability.** The engineering cost talent training program has integrated practical teaching elements from aspects of theory on educational philosophy, professional disciplinary group construction, talent training program revision, course system design, teaching staff construction, evaluation, and guarantee, in an effort to strengthen students' comprehensive abilities. As required by the talent training program for the engineering cost specialty, the CEMV course should form course support regarding practical abilities in aspects of project investment and financing analysis and planning, construction engineering cost determination and control, construction cost control, auditing, identification of cost disputes, contract management, risk management and control, and solving of practical cost management problems in the whole project construction process. Practical project teaching arrangements have been made for earth and stone work calculation, masonry work calculation, reinforcing steel bar and concrete engineering quantity calculation, and decoration engineering quantity calculation. Given that the actual construction cost work is faced with whole projects instead of separating relatively independent knowledge points from teaching materials, a two-week practical training class was specially set in two different directions: civil engineering and installation engineering. Moreover, the dispersed knowledge points of the CEMV course were organically integrated in a project-driven manner to afford the students with systematic training of their practical abilities at cost positions under real engineering scenarios and post.

**Normalization.** Distinct from other pure technical codes, standards, and regulations, those specific to engineering costs lay greater emphasis on the goal definition, description, requirements, and handling methods to standardize human behaviors and the cost work. Engineering cost consultation serves socioeconomic construction and is supported by national-level legal basis, with solemn legal liability and obligation relations. Hence, engineering cost-related work shall be done in accordance with relevant laws and regulations currently in force in China, further requiring professional talent education in colleges and universities to pay high attention to the cultivation of professional qualities. Therefore, this course design must fully combine the current laws and regulations, construction specifications, technical regulations, and standard schematic handbooks in China. The teaching and practical training process shall be done in strict accordance with mandatory requirements specified in such code standards. Engineering cost documents should be prepared according to model texts to standardize the operation process and professionalize industrial fields.

### 4.4 Course design after reform

The engineering cost course teaching is characterized by broad teaching contents, large professional span, and strong course systematic nature. Thus, core knowledge should be accurately mastered in the course design and thought. In addition, theoretical knowledge, practical skills, and practical application environment should be combined into a whole to develop and design teaching models while cultivating students' comprehensive ability to complete whole construction projects as the key point. The CEMV course is a required course of the engineering cost specialty. Based on courses such as building construction and architectural structure, this course aims to familiarize students with engineering cost-related laws, regulations, and industrial standards; enable them to master the calculation methods for engineering costs; and cultivate their abilities to carry out construction project settlement, budgeting, and engineering cost consultation. These goals serve as the basis for learning the engineering cost specialty and taking engineering cost-related jobs. Through the course learning, students are required to master the basic principle of construction project quotas, calculating engineering quantities and determining engineering costs. In the professional ability modularization of the talent training program, five courses—CEMV, IEMV, Application of Cost Estimating Software, Practice of CEMV, and Practice of IEMV—are integrated to form a course system support for goal attainment modularization, expecting to train and cultivate students' ability to prepare construction project estimates and budgets. The main course contents are as follows: project construction procedures and valuation system; construction engineering consumption quotas and the valuation method for the unit price of manpower, materials, and machines; construction engineering costs; engineering pricing basis and method; engineering quantity calculation and valuation; engineering estimates and budgets; construction project settlement and final accounting upon completion; and application of engineering cost estimating software and BIM technology.

### 4.5 Theoretical foundation of teaching evaluation

**Theoretical foundation of teaching.** This course design is based on the OBE. Focusing on core ability cultivation and core knowledge architecture establishment of the engineering cost specialty, the core functional elements and course ability matrix should be fully considered, teaching outcomes will be formed after student-centered course learning, and the teaching effect will be assessed according to the teaching outcomes. By learning this course, students are required to master the labor, material, and machinery consumptions in construction consumption quotas; determine unit prices; systematically introduce the composition of construction costs; master the measurement of engineering quantities; determine comprehensive unit prices; master calculation methods and steps for construction costs through classroom teaching and homework exercises; and comprehend the application methods of engineering cost-related computer software. Through knowledge learning and practical training, students will possess the practical valuation ability based on relevant pricing theories, especially the ability to prepare construction drawing estimates.

**Theoretical foundation of teaching evaluation.** When it comes to multiple evaluation theory, not less than two methods are adopted to measure learners' learning outputs during the course teaching quality evaluation process. Not restricted to the single form of examinations or tests, abundant measurement methods will be used, including classroom performance, practical operation evaluation, online performance, and team performance. Multiple evaluation approaches not only highlight the pluralism of evaluation ideas, contents, subjects, and methods, they also lay greater emphasis on diversified learning methods and ability representation, which aim to realize individualized cultivation of learners. Based on multiple evaluation theory, a course evaluation model containing 22 evaluation indexes in 5 dimensions was constructed. Next, index weights were allocated using the FAHP method to evaluate the teaching quality of the CEMV course and provide reference for course evaluation in similar colleges and universities.

**Dynamic development model of teaching evaluation.** The ultimate goal of course evaluation lies in promoting the teaching quality, measuring students' mastery of core knowledge in the course outline, quantitatively evaluating teachers' course teaching outcomes, and improving the transformation efficiency and achievement level of core abilities in engineering education from the perspective of teaching outcomes. In this research, a dynamic development model (Figure 3) of course teaching evaluation was constructed according to the implementation process of course teaching, which was a closed-loop progressive development model of teaching management, i.e., the "conceptual transition" of the power source for course evaluation → "mobilization and commitment" of whole staff participation → all-round "preparation and planning" → "operability" of teaching evaluation schemes → "examination and evalution" of teaching process → "reinforement and enhancement." Scholars have generally accepted that the dynamic development period of university teaching evaluation lasts for 3–5 years [21], which conform to the updating period of university teaching evaluation standards and systems.

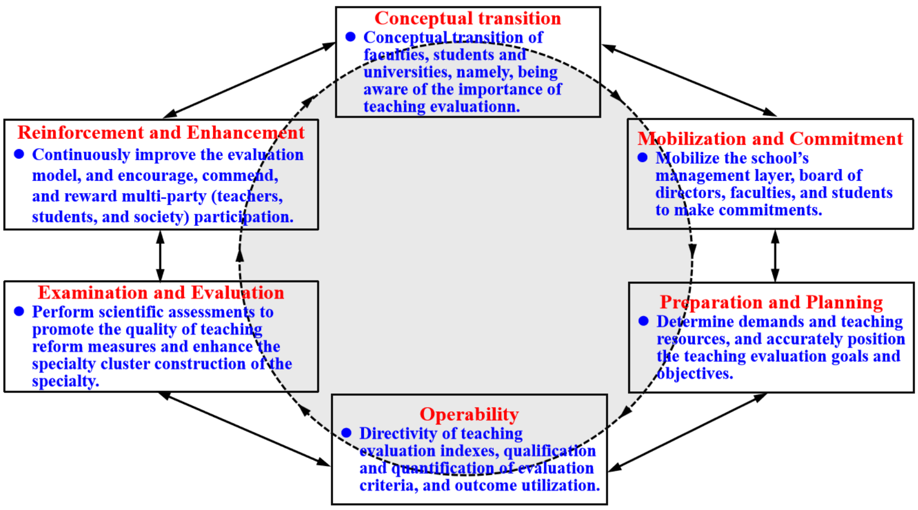


**Fig. 3.** Dynamic development model of teaching evaluation

## 5 Conclusions

In this study, an evaluation model for the CEMV was established through the FAHP method by combining the characteristics of the engineering cost specialty, thereby realizing the fine evaluation of professional course teaching. Finally, the following conclusions were drawn:

(1) An evaluation index system consisting of 22 evaluation indexes in 5 dimensions was constructed according to the characteristics of the engineering cost specialty-related core course. Moreover, a professional course teaching quality evaluation model was established on the basis of the FAHP method, and a trigonometric fuzzy function was introduced. Experts compared and judged the fuzzy interval of comments to realize the quantitative analysis of judgment and index scores. The teaching evaluation grades and conclusions were quantitatively calculated. This teaching quality evaluation model and evaluation method are also applicable to specialties such as bioengineering, clinical medicine, mechanical engineering, and computer.

(2) According to the local industrial laws and regulations, the design of this engineering cost specialty-related course should be closely associated with the industry and standardization, thus endowing the course with features such as regionalism, timeliness, practicability, and normalization. These features were considered in the course design, teaching, and quality evaluation after the teaching innovation.

(3) The course teaching quality evaluation was based on the theory of outcomes-based education and multiple evaluation approaches. A closed-loop (“conceptual transition → mobilization and commitment → preparation and planning → operability → examination and evalution → reinforement and enhancement”) progressive development model of teaching management was constructed. In addition, the evolutionary process and driving pattern of course teaching evaluation were expounded.

As for the contributions of this study, fine course teaching evaluation indexes were selected. In addition, a set of relatively objective evaluation index system was formed, which could comprehensively and truthfully reflect the teaching-learning synergistic effect. Undeniably, the pertinent fine course teaching quality evaluation system should be continuously optimized in the teaching practice. To better promote the fine teaching quality evaluation, the following suggestions were proposed: i) Professional course evaluation index systems and evaluation models should be constructed on the bases of the characteristics of each discipline. University teaching evaluation is a meticulous and complex systematic work. In this research, the evaluation index system specific to a professional course was established on the bases of the characteristics of the engineering cost specialty. However, the differences in the subject category, professional background, evaluation object, main evaluation agency, and outcome utilization should be fully considered in practical teaching management. Hence, the pertinent fine course teaching quality evaluation system should be continuously optimized in the teaching practice, which is a follow-up research direction. ii) A comprehensive platform integrating teaching management, teaching design, teaching data acquisition, and teaching evaluation can be developed by combining technologies such as big data, artificial intelligence (AI), Internet of Things (IoT), 5G technology, and cloud computing. The AI technology can be used to realize pertinent data crawling and analysis based on the whole-teaching-process recording and automatic data acquisition, thereby promptly evaluating classroom teaching quality and providing dynamic feedback over the teaching effect. This process helps teachers promptly determine problems during the whole teaching process and promptly adjust the course design and teaching method. iii) High-quality "model" courses and their evaluation criteria can be established according to the subject category. Colleges and universities prevalently differ in school-running orientation, faculty, and management level, which will certainly lead to their differences in terms of teaching quality. Hence, high-quality "model" courses can be set up through course normalization design and unified evaluation criteria to evaluate similar courses in different colleges and universities according to the evaluation criteria for such model courses. Moreover, their gaps should be continuously narrowed to improve the overall course level, based on which they can seek further characteristic development.

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