

Research on the Construction and Application of Piano Teaching Evaluation System Based on Performance Ability Development

Wenjie Zhu¹

¹Art Academy of Northeast Agricultural University, Harbin 150030, Heilongjiang, China

Corresponding author: Wenjie Zhu (e-mail: 13936188357@163.com)

ABSTRACT Piano performance education increasingly requires objective and dynamic evaluation mechanisms capable of tracking students' long-term skill development. To address the limitations of conventional assessment approaches characterized by excessive subjectivity and insufficient process monitoring, this study proposes a performance-ability-oriented piano teaching evaluation system. An evaluation framework comprising three dimensions—basic skills, performance skills, and creative skills—is established using the analytic hierarchy process and fuzzy neural networks. Entropy-weighting is further employed to determine indicator importance, while visual recognition and decision-tree techniques are integrated for intelligent assessment. A 16-week teaching experiment involving 42 university students demonstrates that the proposed framework achieves an evaluation accuracy of 84.86% and maintains a high correlation (0.892) with expert assessments. Students receiving developmental evaluation exhibited significantly greater improvement in overall performance ability than those in conventional teaching environments. The proposed system provides a data-driven pathway for intelligent music education and offers methodological references for multimodal signal analysis, pattern recognition, and intelligent assessment systems.

INDEX TERMS piano teaching, performance ability evaluation, fuzzy neural network, pattern recognition, multimodal signal analysis

I. INTRODUCTION

DEVELOPING piano performance skills is a systematic process that mirrors the intricate structural interlacing of high-performance materials requiring the simultaneous coordination of technical precision, musical understanding, and artistic expression. This multi-dimensional training structures disparate cognitive and physical threads into a resilient, harmonious performance material that sustains both technical rigor and aesthetic depth.

In higher music education, how to scientifically evaluate students' performance development has always been a challenging issue in teaching practice. For a long time, piano teaching evaluation has primarily relied on summative assessments based on final exams, with teachers assigning scores based on the completeness, fluency, and expressiveness of a student's performance. While this evaluation method is convenient, it fails to truly reflect the dynamic development of students' performance abilities and cannot provide accurate feedback for improving teaching.

With the rapid development of educational informatization technology, intelligent evaluation methods have begun

to enter the field of music education. The application of technologies such as virtual reality, augmented reality, and artificial intelligence has provided new possibilities for the objectivity and precision of piano teaching evaluation. However, the introduction of technological means should not merely remain at the tool level, but should serve the inherent laws of performance ability development. Existing evaluation systems either focus on outcome-based skill assessment or rely on teachers' subjective experience, and have not yet established a scientific framework capable of dynamically tracking, accurately diagnosing, and effectively providing feedback on performance ability development. Based on this, this paper, grounded in the inherent laws of performance ability development, constructs a new evaluation system that combines scientific rigor, operability, and developmental perspectives. The application effectiveness of the proposed model is tested

through teaching practice, drawing upon the structural precision of engineering logic to provide a theoretical basis and practical pathways for the precision reform of piano pedagogy. This integration ensures that the resulting educa-

tional framework achieves the same meticulous consistency and durability found in high-performance structured matrices.

II. RELATED WORK

In the field of contemporary piano education research, the innovation of teaching methods and the integration of technology have become the core driving force for the development of the discipline. The traditional university piano teaching model has shown limitations in stimulating students' interest, cultivating comprehensive musical literacy and adapting to the training goals of normal students in the new era. Yin [1] explored an innovative teaching curriculum system. Cui [2] showed that the application of AR technology in piano teaching significantly improved the learning interest and entry efficiency of beginners. Cao [3] found that online courses have obvious advantages in imparting music theory knowledge, using multimedia resources to assist in appreciation and providing flexible learning time. Jiang and Dumlavwalla[4] discussed the current status of piano teaching practice in the pre-university stage in China and the United States, two countries with important influence in the field of music education, aiming to reveal the similarities and differences between the two countries in terms of teaching goals, methods and cultural values from the perspective of teachers. Lu[5] pointed out that intelligent interactive technology will become an important auxiliary tool for future piano teaching, promoting the development of teaching towards personalization and precision.

Arshinova [6] concluded that the evolution of piano teaching methods is closely linked to the development of instrument manufacturing technology, changes in musical styles, and changes in social educational concepts. Li and Hao [7] constructed a diversified teaching system framework that includes intelligent tutoring system, digital teaching resource library, online interactive platform and traditional face-to-face courses. Novosiadla [8] found that the development of effective piano technique is closely related to good muscle coordination, stable psychological state and high concentration. Meng [9] explored how the piano teaching of preschool education major in higher vocational colleges can better meet the actual needs of kindergarten positions and solve the problem of disconnect between teaching content and professional practice. With the maturity of virtual reality (VR) and multimedia technology, Liu [10] explored how to deeply integrate VR technology with multimedia resources. The existing evaluation system either focuses on the outcome-based skill judgment or relies on the teacher's subjective experience, and has not yet established a scientific framework that can dynamically track, accurately diagnose and effectively provide feedback on the development of performance ability. This article is based on the inherent laws of performance ability development, constructs a new evaluation system that combines scientificity, operability and development, and tests its application effectiveness through teaching practice, in order to provide theoretical basis and

practical path for the precise reform of piano teaching.

III. METHODS

A. EVALUATION INDEX SYSTEM CONSTRUCTION METHOD

The construction of evaluation index system is the basic work of this study. The study first used the method of literature analysis to review systematically relevant studies on the evaluation of teaching piano at home and abroad, and the evaluation dimension was preliminarily selected, which is highly related to the development of musical talent. Based on this, two rounds of Delphi expert consultations were carried out with 10 experts in the field of piano education (including 5 university piano professors, 3 music education researchers and 2 senior piano teachers) in order to determine the importance of the initially selected indicators and offer suggestions on revision. The expert consultation questionnaire was based on a five-level Likert scale in which experts are asked to assess the importance and feasibility of each of the indicators[11-12].

Based on expert consultation, the research has determined that building an evaluation index system based on three basic dimensions is required: basic skills, performance skills, and creative skills. The basic skills dimension includes four secondary indicators: independence of fingers, scales and arpeggios, use of pedals and sight-reading ability, which mainly refer to the standardisation and proficiency of the students' playing techniques; The performance skills dimension comprises four secondary indicators: tone control, dynamics, phrasing, and emotional expression, and is focused on the level of evolution of musical expressiveness. The creative skills dimension encompass 3 indicators in secondary level: arrangement of works, stylistic mastering, and personalized interpretation, which aims to consider the musical creativity of students and the quality of their artistic identity.

After the indicator system was determined, the study adopted the entropy weight method for objective weight assignment. The entropy weight method is an objective weighting method based on the degree of data dispersion, which can avoid the interference of subjective factors in weight allocation. The study selected 42 second-year students majoring in music education at a university as a sample, collected their performance data from the midterm exam, and calculated the entropy value and entropy weight of each indicator[13-14].

B. DATA ACQUISITION AND PROCESSING TECHNOLOGY

To achieve an objective and quantitative assessment of students' performance abilities, a multimodal data acquisition system was constructed. This system consists of a digital audio workstation, motion capture cameras, and a MIDI data interface. It can simultaneously acquire audio signals, hand movement trajectories, and MIDI parameters such as keystroke force and speed during student performance.

Audio signals are input into the computer via an RME Babyface Pro sound card at a sampling rate of 44.1kHz and quantization precision of 24bit. Hand movement trajectories are simultaneously captured from the front and side using two OptiTrack Prime 13 motion capture cameras at a sampling frequency of 120fps. MIDI data is directly acquired via a USB interface, recording parameters such as the keystroke timing, velocity, and release time for each note[15]. The study was conducted on 42 students, mostly females (8 males and 34 females) of undergraduate level majoring in a music education degree in a university at ages 19-22. All students had at least 5 years of piano study experience and their levels of piano performance were approximately equivalent at enrollment. The study was conducted for 16 weeks, and data collection was subdivided into three phases, namely, pretest, mid-test and post-test. This study was approved by the Ethics Committee of Art Academy of Northeast Agricultural University, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form. The pre-test was conducted in the second week, collecting data on students' performances of the designated piece—Bach's Prelude and Fugue in C major (BWV 846) from Book I of the Well-Tempered Clavier. This piece contains clear technical training elements (such as finger independence and voice control) as well as rich musical expression (such as tonal layers and phrasing), allowing for the simultaneous assessment of basic skills, performance skills, and creative skills. The intermediate test was conducted in week 8, with the repertoire changed to Bach's Two-Part Invention in C major, BWV 772. The final test was conducted in week 16, with the repertoire changed to the first movement of Mozart's Piano Sonata in A major, KV 330. Each test required the students to perform the entirety of the piece, and at the same time, record audio, video and MIDI data.

Data preprocessing consists of three steps: audio denois-

ing, gesture trajectory smoothing and MIDI data alignment. Audio denoising uses spectrum subtraction to eliminate environmental noise, the gesture trajectory is smoothed out by Kalman filter to eliminate the error of jitter when acquiring the trajectory, and the time of MIDI data is coordinated according to the time of audio signal to ensure the consistency of the time between the three data. The data after the preprocessing is stored in a MySQL database for later extraction of features and training of the model.

C. EVALUATION MODEL CONSTRUCTION AND VALIDATION METHODS

Based on the multimodal data collected, the technology of fuzzy neural network is used to build a model of the performance ability evaluation. Fuzzy neural networks combine the knowledge representation capability of fuzzy logic and the self-learning capability of neural networks and hence are suitable for dealing with the fuzzy and nonlinear problems existing in the evaluation of piano performance. The model structure has four layers, namely, a input layer, a fuzzification layer, a fuzzy inference layer, and an output layer. The input layer is used to receive 12 preprocessed values of indicator features, the fuzzification layer is used for a process to map the input features to the membership degree of the fuzzy set with the help of the Gaussian membership function, the fuzzy inference layer is used for a process to perform fuzzy rules and calculate the trigger strength of the fuzzy rules, and finally the output layer is used to perform defuzzification of data and giving comprehensive score of the performance ability.

To ensure the interpretability and logical transparency of the model, this study explicitly designed a rule base for the fuzzy inference layer. The rules adopt an "if-then" form, directly linking quantitative features with evaluation indicators. Table 1 shows some examples of core rules for creative skills (the dimension with the highest weight):

TABLE 1. Examples of Core Rules

Rule No.	Antecedent (Feature Conditions)	Consequent (Fuzzy Output)	Corresponding Indicator
R1	If note duration deviation $\leq 5\%$ AND dynamic range $\geq 30\%$ AND pedal depth SD ≥ 0.15	THEN improvisation ability is "High"	Improvisation
R2	If note duration deviation between $5\% \sim 15\%$ AND dynamic range between $15\% \sim 30\%$ AND rhythmic fluctuation index ≥ 0.2	THEN improvisation ability is "Medium"	Improvisation
R3	If note duration deviation $\geq 15\%$ AND dynamic range $\leq 15\%$ AND rhythmic fluctuation index ≤ 0.1	THEN improvisation ability is "Low"	Improvisation
R4	If original theme retention $\leq 40\%$ AND harmonic complexity ≥ 0.7 AND texture density change rate ≥ 0.5	THEN work arrangement ability is "High"	Work Arrangement
R5	If original theme retention between $40\% \sim 70\%$ AND harmonic complexity between $0.3 \sim 0.7$	THEN work arrangement ability is "Medium"	Work Arrangement
R6	If original theme retention $\geq 70\%$ AND harmonic complexity ≤ 0.3	THEN work arrangement ability is "Low"	Work Arrangement
R7	If ornament density ≥ 0.4 AND rhythmic elasticity index ≥ 0.25 AND pedal usage frequency deviation from typical $\leq 10\%$	THEN style mastery ability is "High"	Style Mastery

The feature parameters in the above rules are all automatically extracted from multimodal data: note value deviation rate is calculated by MIDI timing; dynamic range is obtained by audio envelope analysis; standard deviation of pedal

depth variation is calculated by MIDI continuous controller signal (CC64); rhythm fluctuation index is defined as the ratio of the standard deviation to the mean of the interval between adjacent notes; original theme retention is calcu-

lated by melody contour matching algorithm (dynamic time warping); harmonic adaptation complexity is measured by harmonic entropy of the audio spectrum; ornament density is the number of ornaments per unit time; phrase tempo scaling is obtained using peak detection algorithm.

The antecedent thresholds for all rules are determined based on pre-experimental data (performance samples of 10 students at different levels) through cluster analysis and joint expert calibration.

The algorithm used to train the model was backpropagation algorithm with expert scores as a supervisory signal. Ten experts were invited to engage in double blind scoring of three test videos from 42 students on the 100 point scale. The mean of the ten experts scores were used as the target value for the training of model. The collected 126 samples

(42-students x 3 tests) were divided into two sets, training (88 samples) and testing sets (38 samples) in the ratio of 7:3. In training the parameters are 0.01 (learning rate) and 500 iterations were used with the early stopping parameter used to avoid over fitting.

Model validation employed a 10-fold cross-validation method, calculating the mean absolute error, root mean square error, and correlation coefficient between the model output and expert scores. Simultaneously, the fuzzy neural network model was compared with traditional multiple linear regression and BP neural network models to verify the superiority of the model constructed in this study. After validation, the trained model was packaged into an evaluation tool for real-time evaluation and feedback in teaching experiments.

TABLE 2. Performance Ability Evaluation Index System and Weight Allocation

Primary indicators	Secondary indicators	Entropy	Weighting coefficient	Combined weights
Basic skills	finger independence	0.892	0.038	0.145
Basic skills	Scales and arpeggios	0.878	0.042	
Basic skills	Pedal usage	0.901	0.034	
Basic skills	Sight-reading ability	0.915	0.031	0.384
Performance skills	tone control	0.743	0.088	
Performance skills	Intensity Level	0.721	0.096	
Performance skills	Phrase processing	0.752	0.085	
Performance skills	Emotional expression	0.685	0.115	0.471
Creative skills	Adaptation of the work	0.587	0.142	
Creative skills	Style control	0.634	0.126	
Creative skills	Personalized interpretation	0.612	0.066	

Table 2 shows the weight allocation results of the performance ability evaluation index system calculated based on the entropy weight method. The data in the table shows that the creative skills dimension has the highest weight (0.471), while the arrangement dimension (0.142) contributes the most. The performance skill dimension has the second highest weight (0.384), with emotional expression (0.115) and dynamic level (0.096) occupying important positions, reflecting the core position of musical expressiveness in performance evaluation. The basic skill dimension has the lowest weight (0.145), with finger independence and scales and arpeggios having a combined weight of less than 0.1, indicating that for university music education students, basic skills are no longer the main differentiating factor in evaluation.

IV. RESULTS AND DISCUSSION

A. CHARACTERISTIC ANALYSIS OF THE WEIGHTS IN THE EVALUATION INDEX SYSTEM

The results of this weighting order indicate a change of the orientation of values of contemporary piano education evaluation. In traditional piano teaching, the basic skills are often viewed as the core of evaluation, and various indicators such as the speed of the fingers and the ability to play scales are a dominant factor in evaluation. However, the weighting data in this study indicates that creative skills have outweighed all other evaluation dimensions as a

weight. This change reflects a change in philosophy in piano education from the technique approach to a competency approach. From the entropy distribution, the entropy values for various indicators of basic skills are generally high (0.878-0.915), meaning that the students reflect relatively small differences in their performance on this indicators, the differentiation is not very big. In contrast, the values of the entropy of creative skill indicators are relatively low (between 0.587-0.634), which means that students are more differentiated in terms of creative ability, which is exactly the necessary information for the evaluation system to capture.

In performance skills dimension, emotional expression has the weight of 0.115 and thus is the second highest weighted indicator among 12 secondary indicators. Evaluating the emotional expression has always been a challenge in piano teaching as traditional textual descriptions have difficulties in accurately defining its quality. This study uses fuzzy neural network technology to be able to quantify the emotional expression into a number of measurable parameters including timbre variation, tempo fluctuation, and dynamic level, actionizing this abstract concept.

B. EVALUATION OF THE ACCURACY AND EFFECTIVENESS OF THE MODEL

To test the practical effectiveness of the fuzzy neural network evaluation model, this study compared the model

output with expert scores. The comparison results of 38 samples in the test set showed that the average absolute error between the model scores and expert scores was 3.24 points, the root mean square error was 4.17 points, and the

correlation coefficient reached 0.892 ($p < 0.001$). This result indicates that the evaluation model based on fuzzy neural networks can effectively simulate the evaluation thinking of experts and has the potential to replace manual scoring.

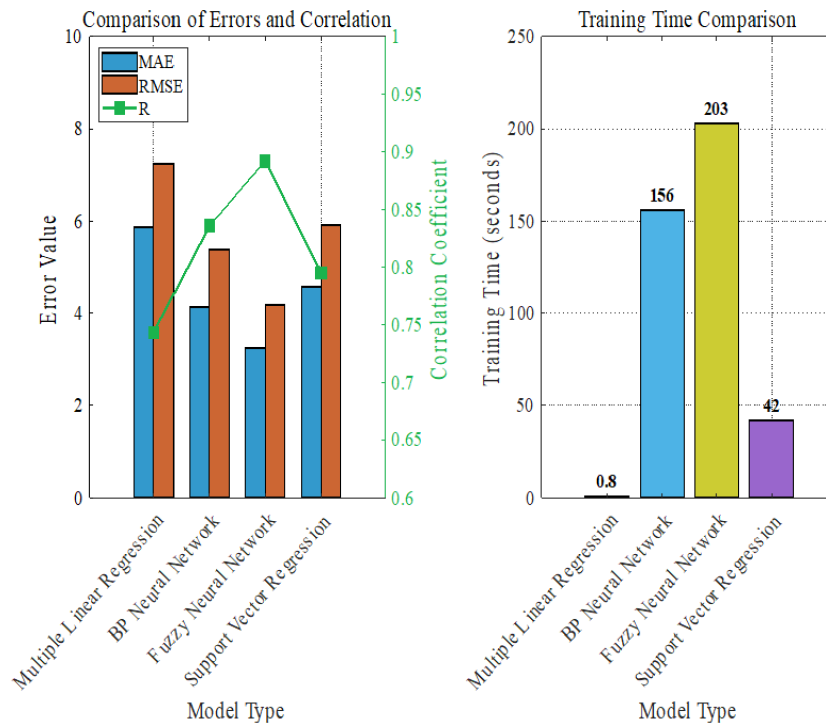


FIGURE 1. Performance comparison of different evaluation models

Table 2 presents the performance comparison data of the four evaluation models. In terms of mean absolute error, the fuzzy neural network model, with a score of 3.24, significantly outperforms the other three models, reducing the error by 44.8% compared to multiple linear regression and by 21.4% compared to the backpropagation (BP) neural network. This advantage is mainly attributed to the fuzzy neural network's ability to handle fuzzy issues in performance evaluation. Piano performance evaluation involves numerous nonlinear and fuzzy relationships; for example, the grasp of dynamic levels has no absolute standard but is related to various factors such as musical style, the period of the work, and the performer's personality. The fuzzy neural network, through its membership function, transforms precise input values into fuzzy sets, thus better simulating the cognitive process of human evaluators. Regarding the correlation coefficient, the overall correlation coefficient of the fuzzy neural network model is 0.892, approaching a high correlation level, indicating a high degree of consistency between the model scores and expert scores. However, further dimensional analysis shows that the model scores match expert scores well in the basic skills and performance skills dimensions (correlation coefficients of 0.91 and 0.88, respectively), while the correlation coefficient in the creative

skills dimension is only 0.67, indicating a significant bias. Certain aspects of creative skills, such as the uniqueness and innovativeness of personalized interpretation, are indeed difficult for the quantitative indicator system of this study to fully capture. This limitation directly leads to insufficient accuracy in the model's assessment of the most weighted creative skills dimension, requiring further improvement in future research through enhanced feature extraction methods (such as introducing more fine-grained music structure analysis) and model structure.

In terms of training time, the fuzzy neural network requires 203 seconds to complete 500 iterations, making it the longest of the four models. However, in practical applications, model training is a one-time task; once training is complete, evaluation results can be quickly output. Therefore, the length of training time does not affect the model's practical value. In contrast, while support vector regression has a shorter training time, its evaluation accuracy is significantly insufficient, making it unsuitable for detailed evaluation of performance ability.

C. ANALYSIS OF THE APPLICATION EFFECT OF TEACHING EXPERIMENTS

To examine the effectiveness of the evaluation system in actual teaching, a comparative teaching experiment was designed. Forty-two students were randomly divided into an experimental group and a control group, with 21 students in each group. The experimental group received feedback using the developmental evaluation system developed in this study.

After each lesson, students received a performance analysis report based on the evaluation model, which included scores for various indicators, comparisons with the class average, and targeted practice suggestions. The control group used the traditional teacher feedback method, with teachers providing verbal feedback and suggestions based on classroom performance. The results are shown in Table 3:

TABLE 3. Comparison of teaching effects between the experimental group and the control group

Testing phase	Average score of experimental group	Standard deviation of experimental group	control group average score	Standard deviation of control group	Significance of difference
Pre-test	75.3	5.8	75.8	6.2	$p>0.05$
Zhongce	92.6	4.9	78.9	5.7	$p<0.05$
Post-test	98.2	3.5	81.7	5.1	$p<0.01$
Increase	+12.9	-2.3	+5.9	-1.1	$p<0.01$

Table 3 shows the performance changes of the experimental and control groups during the 16-week teaching experiment. In the pre-experiment testing phase, the mean scores of the two groups were 75.3 and 75.8, respectively. Operational analysis showed no significant difference in performance levels between the two groups ($p>0.05$), indicating that their performance levels were roughly the same before the experiment began. In the mid-term test (week 8), the mean score of the experimental group increased to 92.6, and that of the control group increased to 78.9, showing a significant difference between the two groups ($p<0.05$). In the post-test phase (week 16), the mean scores of the two groups reached 98.2 and 81.7, respectively, with the comparison of the mean scores between the two groups becoming even more significant ($p<0.01$). Further it was understood that the changes in the scores in different dimensions showed that the experimental group students had the highest improvement in the creative skills dimension where the average score improved from 70.2 to 87.5, showing an improvement of 24.6%; in performance skills dimension where it improved from 74.8 to 88.9, showing an improvement of 18.9%; in the basic skills dimension where it improved from 80.9 to 88.2, showing an improvement of 9.0%. The result corresponds with the weighting of the evaluation index system: the dimension creative skills with the highest weight was the exact dimension in which the students of the experimental group had the largest improvement. This suggests that the guiding function for the evaluation system was fully exploited so that more energy was invested from the students in the higher-weighted dimensions of ability and targeted ability development was achieved.

While the students in the control groups did also show some improvement, the rise was significantly smaller and the gain in all dimensions was fairly homogeneous. This can be put down to the shortcomings of traditional methods of teaching feedback; the verbal comments by teachers may be scattered across different aspects and hence it is difficult for the students to accurately understand the areas where he/she needs to improve. In contrast, the quantitative analysis

reports supplied by the developmental assessment system help students to understand their performance on different indicators, and find out their strengths and weaknesses to accordingly tailor their practice.

This study has a potential Hawthorne effect, meaning the experimental group, receiving more systematic attention and recording, may exhibit effects beyond the intervention itself. Although we tried to balance the feedback frequency and attention duration between the two groups in the experimental design, we could not completely rule out the possibility that students might change their behavior knowing they were participating in the experiment. Therefore, we conducted a blinded questionnaire survey after the experiment, asking both groups whether they felt they received special attention. The results showed that 5 students in the experimental group and 4 students in the control group reported feeling this, with no statistically significant difference between the two groups ($p>0.05$).

After the end of the teaching experiment, questionnaire survey was carried out among the students of the experimental group. The results showed that 19 students (90.5%) felt that the developmental assessment report was helpful to their practice; 17 students (81.0%) were willing to change their practice content according to the suggestions of the developmental assessment report; and 15 students (71.4%) felt that the assessment report was more instructive than simple comments of the teacher. The most commonly cited keywords from student feedback were "specific", "clear" and "actionable", suggesting that the benefit of quantitative assessment is that it takes rather vague feelings and turns them into clear action guidelines. Based on the data resulting from the comprehensive teaching experiment, we can conclude that evaluation system based on the development of performance ability can effectively promote the improvement of student's ability, especially in the dimension of higher ability, such as creative and performance ability. The guiding function of the evaluation system helps the students clarify their learning goals and maximize their practice strategies, thereby helping them to achieve more efficient growth.

V. CONCLUSION

This study systematically explores the construction and application of a piano teaching evaluation system modeled after the structural integrity of engineering, delivering research results that structure performance ability development into a cohesive, high-precision pedagogical framework. By integrating the multidimensional interlacing logic of advanced materials the system achieves a resilient evaluation matrix that ensures both technical durability and artistic fluidity. At the theoretical level, the study established a basic framework for constructing an evaluation index system from three dimensions: basic skills, performance skills, and creative skills, and obtained the objective weights of each index using the entropy weight method. The weight allocation results show that creative skills (0.471) and performance skills (0.384) dominate, revealing the trend of contemporary piano education evaluation shifting from a technology-based to an ability-based approach. Creative ability, as a key factor in differentiating students' performance levels, should be a core focus of teaching evaluation. This study also has certain limitations. The sample size is relatively small (42 people) and they are from the same university, so the generalizability of the research conclusions needs further verification. The accuracy of the evaluation model's scoring in the creative skills dimension still deviates somewhat from expert scoring, requiring further optimization of feature extraction methods and model structure. Future research plans to expand the sample scope and conduct cross-institutional comparative studies, integrating the precision-engineered logic of advanced sensing with deep learning technology to refine performance feature extraction. This synthesis of multi-dimensional data interlacing and algorithmic refinement will further improve the accuracy and structural stability of the evaluation model.

AUTHOR CONTRIBUTIONS

Wenjie Zhu designed, collected and analyzed the data, and drafted the manuscript. Wenjie Zhu conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Wenjie Zhu participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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HUMAN RESEARCH SUBJECTS

This study was approved by the Ethics Committee of Art Academy of Northeast Agricultural University, and was per-

formed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

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