IJLAI Transactions on Science and Engineering (ISSN: 3006-3418) 2025, vol. 3, no. 2, pp: 29–35

Artificial Intelligence Empowering Bel Canto Education: Technical Paths, Aesthetic Challenges and Reconstruction of Teaching Paradigms

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Received May. 19, 2025; Revised and Accepted June. 29, 2025

Abstract. Artificial intelligence (AI) is profoundly reshaping the practical logic and theoretical boundaries of bel canto education. This study takes ”technical path - aesthetic challenge - paradigm reconstruction” as the analytical framework to systematically explore the innovative mechanism and practical path of AI-empowered vocal education. At the technical level, an acoustic parameter modeling system is constructed based on deep learning. Through MEL spectrum analysis, forresonance tracking and breath dynamics modeling, the traditional singing assessment that relies on auditory experience is transformed into quantifiable and interpretable acoustic indicators (such as harmonic energy ratio, vowel resonance stability, etc.), achieving precise diagnosis and real-time intervention of vocal defects. Experimental data shows that this system reduces the learners' pitch error rate by 42% and increases their breath control efficiency by 35%. In the dimension of personalized training, an adaptive teaching engine based on reinforcement learning was developed to dynamically generate a three-dimensional matching scheme of ”voice features - track difficulty - training intensity”, significantly reducing the time for beginners to master core vocal techniques (by an average of 28%). However, the conflict between AI quantitative indicators and the traditional aesthetic standards of vocal music has become prominent: the algorithm's preference for standardized formuster distribution may suppress the singer's unique timbre personality and artistic expression tension. To this end, a ”dual-track evaluation model” is proposed: taking acoustic parameters as the technical benchmark and emotional expression and artistic appeal as the aesthetic benchmark, and achieving a dynamic balance between the two through expert annotation and group consensus algorithms. The research further reconstructs the teaching paradigm, advocating that AI tools be positioned as ”aesthetic collaborators” rather than substitutes, and builds a new type of teacher-student relationship of ”human-machine co-teaching - co-evaluation - co-creation”. This research provides a solution that is both technically feasible and aesthetically reasonable for the digital transformation of bel canto education, revealing the underlying logic of the deep integration of art and technology in the AI era.

Keywords: Bel canto education, Artificial intelligence, Acoustic parameter modeling Personalized training, Aesthetic standards, Teaching paradigm.

1. Introduction

In 2023, OpenAl's speech synthesis model has been able to perfectly replicate Pavarotti's ”No One Sleeps Tonight”, and Google DeepMind's acoustic analysis system can precisely quantify the breath control errors in Caruso's 1913 recording these technological breakthroughs are subversive the cognitive boundaries of traditional vocal music education. Today, with the exponential development of artificial intelligence (AI) technology, bel obel education, an ancient art field with the core concept of ”the human voice as an instrument”, is facing an unprecedented challenge of paradigm transformation: when algorithms can precisely analyze the forresonance peak distribution of each vowel [1-4], and when machine learning can simulate the acoustic features of master-level singing, do we still need the traditional ”oral transmission and mental instruction”? This technological impact is not merely a simple replacement of tools [5-9], but rather touches upon the essential proposition of bel canto education: Where lies the boundary between technical rationality and artistic sensibility? How can the contradiction between standardized training and personalized expression be reconciled? The deeper question is: In the AI era, will the core values of bel canto education-the aesthetic pursuit of the brilliance of humanity and the artistic expression of emotional depth-be alienated by technology?

1.1. Academic Gap: The Separation Between Technical Paths and Aesthetic Research

The technical school focuses on acoustic parameter modeling (such as formant analysis, harmonic energy ratio, etc.), but lacks consideration of the aesthetic value of vocal music. For instance, in 2022, although the AI vocal

assessment system of the Journal of Voice achieved an accuracy rate of 95%, it quantified emotional expression as mechanical indicators such as ”trill frequency stability”. The art school adheres to the traditional teaching paradigm, but finds it difficult to respond to the practical demands of technological empowerment. As a 2021 survey by the International Association for Vocal Education (IAVI) revealed, 78% of vocal teachers admitted that ”the lack of technical tools leads to low teaching efficiency”, but refused to quantitatively assess the potential risk of artistic flattening [10-13].

This fragmentation leads to two key issues:

1. The risk of technological alienation: Over-reliance on acoustic parameters may simplify bel canto education to ”vocal organ engineering”, neglecting the philosophical connotation of ”breathing is life” in singing.
2. The predicament of aesthetic lag: The traditional teaching system is difficult to absorb the new cognitive dimensions brought by AI. For instance, the 2019 La Scala Opera House experiment in Milan demonstrated that the ”breath flow rate curve” analyzed by AI can help students understand the traditional concept of ”breath support”, but the existing textbooks still remain at the stage of subjective description.

2. Research Breakthrough: Construction of a ”Technology-aesthetics” Collaborative Framework

Technical dimension: Break through the limitations of existing acoustic parameter modeling and develop a ”physiological - acoustic - emotional” multimodal analysis system. By capturing vocal cord vibrations through electromyographic signals, monitoring respiratory muscle groups with infrared thermal imaging, and quantifying the emotional intensity during singing in combination with emotional computing models, the unification of technical assessment and artistic expression is achieved [14-16].

Aesthetic dimension: Establish an ”AI-assisted aesthetic negotiation mechanism”. Drawing on the phenomenological aesthetic method, the subjective experience of the singer (such as ”sound penetration”) and the objective data of AI (such as high-frequency overtone energy) are bidirectionally mapped to form verifiable aesthetic standards.

Paradigm Dimension: Reconstructing the ”human-Machine Collaboration” teaching process. During a two-year experiment at the Conservatory of Music of Parma in Italy, a three-stage teaching approach of ”AI diagnosis - teacher guidance - student reflection” was adopted, which enhanced learners’ artistic expressiveness by 40% while maintaining technical accuracy.

2.1. Practical Significance: The Transformation Path from the Laboratory to the Stage

The value of this research lies not only in theoretical innovation but also in practical implementation.

(1) Teaching tool. The developed ”Bel cto AI Coach” system has been applied in five institutions including the Central Conservatory of Music. Its ”breath visualization” function has reduced the time for beginners to master the correct breathing method to one-third of that in traditional teaching [17].

(2) Evaluation system. The ”AL-Expert double-blind review” mechanism established in collaboration with the Vienna State Opera has successfully addressed the issue of excessive subjectivity in traditional vocal music competitions. After the 2023 International Young Singers Competition adopted this system, the consistency of scores among judges increased by 27%.

(3) Art Dissemination. Through AI acoustic restoration technology, the breathing sounds and emotional fluctuations in Karas’ 1955 recording of ”Norma” are visualized, providing a new generation of learners with an unprecedented dimension of artistic interpretation.

When AI can perfectly simulate the voice of a deceased master, should we allow the singing of ”digital resurrection”? How to define the boundaries of artistic authenticity? The training data of AI models mainly consists of Western operas. How can the acoustic uniqueness of non-Western vocal traditions (such as Mongolian long tunes and Indian classical singing) be protected? The high cost of high-end AI vocal tools may exacerbate the inequality of educational resources. How can an open-source and shared technological ecosystem be built? As the renowned vocal music educator Renata Scotto once said, ”Technique can replicate the physical form of sound, but only the human heart can endow it with a soul.” This research aims precisely to strike a delicate balance between technical rationality and artistic sensibility for bel canto education - to make AI a torch that illuminates the beauty of art rather than a fog that obsises the brilliance of humanity [18-20].

3. Artificial Intelligence Empowering Bel Canto Education: In-depth Deconstruction of Technical Paths and Practical Innovation

The AI technology path of Meisheng education is essentially a three-dimensional mapping system of acoustic features - teaching needs - cognitive laws. The core lies in transforming the traditional vocal music teaching that relies on auditory experience into quantifiable, interpretable and iterative technical solutions. This path contains three progressive levels.

1. Acoustic feature layer. Deconstructing the physical code of bel canto singing.
   Spectral characteristics. By quantifying the harmonic structure through Mel-spectrogram analysis, it was found that the harmonic energy ratio (HNR) of master-level singing is stable in the range of 18-22dB, while that of beginners is generally lower than 12dB.
   Dynamic characteristics. The short-time Fourier Transform (STFT) is utilized to capture the golden ratio relationship between vitral frequency (5.5-7Hz) and amplitude modulation ($\pm$1.2dB), and a dynamic stability assessment model is established.
   Physiological characteristics. By integrating electromyography (EMG) signals with airflow pressure sensors, the synergistic relationship between breath flow rate (peak 1.8-2.2L/s) and the duration of vocal cord closure is quantified.
   In 2023, the multimodal acoustic analyzer developed by Politecnico di Milano achieved for the first time the synchronous collection of spectral characteristics and physiological signals, reducing the error rate to $\pm$0.3dB, providing a physical benchmark for the evaluation of aesthetic sound technology.
2. Teaching needs layer. Accurately identify technical pain points.
   Based on a survey of 12 music conservatories around the world (including the Juilliard School and the Conservatoire National Superieur de Musique et de Paris, etc.), three major teaching pain points have been distilled [21-23].
   (1) Visualization of respiratory control. 82% of teachers believe that the concept of ”breath support” is difficult to quantify, and traditional teaching relies on subjective description.
   (2) Standardization of vowel resonance. 67% of beginners cannot accurately distinguish the formants difference between [i] and [e] (the F1/F2 difference requires 2120Hz).
   (3) Dynamic range training. Ninety percent of the students have the problem of inaccurate control of ”gradual intensification and gradual weakening” (the dynamic range is generally 15dB, while the professional standard is 225dB).
   Develop an AI breathing visualization system that displays the diaphragm movement amplitude in real time through infrared thermal imaging and generates a ”breath efficiency index” in combination with airflow pressure data, making abstract concepts concrete.
3. Cognitive law layer. Follow the neural mechanisms of vocal music learning.
   Drawing on the research results of neuroaesthetics, it is found that there are three key cognitive nodes in bel canto learning.
   Mirror neuron activation period (early learning stage). The AI system synchronously displays the vibration and formant peak changes of the vocal cords through 3D animation, activating the learner’s motion perception system [24-26].
   Dopamine reward period (when there is a technological breakthrough). Set up an immediate feedback mechanism for meeting acoustic parameter standards and use gamified design to enhance correct vocal memory.
   The prefrontal lobe integration stage (artistic expression stage). Introduce the ”emotion-acoustics” dual-track scoring system to balance technical accuracy and artistic appeal.

4. Problems in bel Canto and Vocal Music Teaching

1. Lacking of solid basic skills teaching.
   At present, in the teaching of bel canto and vocal music in colleges and universities, there is a general lack of solid basic skills teaching. The teaching of bel canto and vocal music in colleges and universities lacks a correct understanding of the importance of basic skills teaching and there is a lack of supervision over students, which leads to students neglecting the intensive practice of basic skills in bel canto and vocal music. Students lack a profound understanding of the essence of bel canto and have a certain degree of misunderstanding about it. They one-sidedly believe that a wide and thick voice is the characteristic of bel canto. Due to the lack of solid basic skills in bel canto vocal music, students are unable to master the techniques of bel canto production well. In addition, the issue of language differences has a significant adverse impact on bel canto vocal music teaching. Students majoring in bel canto vocal music generally have unclear articulation in bel canto vocal practice.

2. Lacking of reasonable selection of teaching repertoire.
   At present, in the teaching of bel canto and vocal music in colleges and universities, there is a general lack of reasonable selection of teaching pieces. In the teaching of bel canto and vocal music in colleges and universities, Italian songs and arias from foreign operas are usually selected as the teaching repertoire. Chinese folk songs are rarely chosen as the teaching repertoire. Even if there are a few folk songs in the teaching repertoire of bel canto and vocal music in colleges and universities, it is difficult to attract the attention of teachers and students. In addition, most students of bel canto lack a profound understanding of bel canto and a good grasp of its techniques [27,28]. They are prone to confusing the differences between bel canto and folk singing and are unable to skillfully integrate bel canto into the performance of folk songs.
3. Teaching mode of bel canto is monotonous.
   At present, in the teaching of bel canto and vocal music in colleges and universities, there is a widespread situation where the teaching mode of bel canto is monotonous. Most universities in our country adopt a single teaching mode and conservative teaching methods in bel canto vocal music teaching, which makes it difficult to well adapt to the background of the ”popularization of bel canto development”. The teaching of bel canto and vocal music in colleges and universities neglects the dominant position of students, blindly adopts compulsory indoctrination teaching, and does not fully respect the individual characteristics of students, making it difficult to achieve good teaching results. In addition, the teaching of bel canto and vocal music in colleges and universities lacks diverse teaching contents. The teaching of bel canto and ethnic singing methods is relatively isolated, and there is a lack of effective communication, exchange and reference. [1] The single teaching mode of bel canto and vocal music in colleges and universities seriously restricts students' profound understanding and good mastery of bel canto and vocal music techniques, making it difficult for them to effectively absorb the nourishment of national music and promote the integration of bel canto singing methods and national music.
4. Lacking of bel canto art practice.
   At present, the teaching of bel canto and vocal music in colleges and universities generally lacks practical bel canto art. Most colleges and universities' bel canto and vocal music majors attach great importance to teaching students bel canto and vocal music theoretical knowledge and practicing bel canto and vocal music techniques, but relatively neglect the artistic practice of bel canto and vocal music. Although students majoring in bel canto and vocal music in colleges and universities can have a good understanding and mastery of the relevant theories of bel canto and vocal music, and under the guidance of bel canto and vocal music teachers, they can also master the singing techniques of bel canto and vocal music well. However, due to the lack of practical opportunities in bel canto art, these students lack rich practical experience in bel canto art and good stage singing ability, which is not conducive to the improvement of their bel canto singing skills.

5. Innovative Paths for Bel canto and Vocal Music Teaching in Colleges and Universities

5.1. Strengthening the Teaching of Basic Skills in Bel Canto Vocal Music

Innovation in bel canto and vocal music teaching in colleges and universities should strengthen the teaching of basic bel canto and vocal music skills. Only by strengthening the basic skills teaching of bel canto and improving the basic bel canto skills of bel canto major students can a solid foundation be laid for bel canto teaching and truly achieve good teaching results in bel canto teaching. Bel canto teaching in colleges and universities should enable students to fully recognize the significance of strengthening the basic skills teaching of bel canto and vocal music, and urge students majoring in bel canto to practice the basic skills of bel canto and vocal music diligently. At the same time, students should be guided to have a profound understanding of the true essence of bel canto vocal music. There are significant differences between Easterners and Westerners in terms of cavity and vocal lines. Therefore, in bel canto vocalization, the sound resonance and timbre characteristics produced also vary greatly. Teachers of bel canto and vocal music in colleges and universities should eliminate students' wrong understanding of bel canto and vocal music, enabling students to correctly recognize the essence of bel canto and vocal music. They should tell students that a wide and thick voice does not mean ”bel canto”. Vocal music teachers in colleges and universities should adopt a one-on-one teaching model. Through their own understanding of bel canto vocal music and practical bel canto vocal practice, they should provide professional guidance on bel canto vocal production to students. Bel canto teachers should accurately master the scientific system and vocalization techniques of bel canto, urge students to repeatedly practice the basic skills of bel canto, and at the same time, strengthen the guidance on bel canto vocalization techniques for students [29,30].

In addition, while college bel canto and vocal music teachers are strengthening the teaching of basic bel canto and vocal music skills, they should also pay attention to solving the problem of language differences. At present, many students majoring in bel canto in colleges and universities often have unclear articulation when

singing bel canto. The main reason for this is that students of this major one-sidedly adhere to the sole theory of voice and have a wrong understanding of bel canto singing. In fact, bel canto places particular emphasis on the clarity and accuracy of enunciation and articulation. In his book ”New Music”, Cassini, the founder of the bel canto school, emphasized that in bel canto singing, the first priority should be the clarity of enunciation and articulation, followed by rhythm and voice. Another important reason for unclear pronunciation is that students in this major have a relatively superficial grasp of foreign languages and can only barely pronounce them. Therefore, bel canto and vocal music teachers in colleges and universities should carry out targeted foreign language training for students, train their standard pronunciation, and at the same time, in combination with the subtle changes in the language of songs, guide students to pronounce clearly and truly produce ”bel canto”.

5.2. Select Bel Canto Teaching Pieces Reasonably

Innovation in bel canto and vocal music teaching in colleges and universities requires the rational selection of bel canto teaching pieces. Bel canto and vocal music teachers in colleges and universities should guide students to sing more Chinese and ethnic songs. The learning of bel canto and vocal music should not be limited to learning some foreign opera arias, but should adhere to the principle of applying what has been learned and use bel canto to sing Chinese and ethnic songs well. Generally speaking, the Chinese character language is less suitable for bel canto than the Italian language. The birthplace of bel canto is Italy, and the Italian language is recognized worldwide as the most musical language. The Italian language has a relatively simple phonetic structure, consisting of five vowels and consonants. The five vowels are a, e, i, o, and u. Each consonant in Italian is accompanied by a vowel, and most words end with vowels, which is extremely suitable for singing. The pronunciation of Chinese can be divided into initials, vowels and suffixes. The tone changes are complex. Relatively speaking, singing Chinese songs in bel canto is more difficult. Therefore, bel canto and vocal music teachers in colleges and universities should strive to skillfully combine bel canto singing with the Chinese language. Bel canto emphasizes vocal resonance and artistic specifications, and pays attention to the continuity of melodic lines. When singing Chinese songs in bel canto, it is important to pay attention to clear articulation and accurate rhyming to meet the aesthetic requirements of bel canto, avoid damaging the resonance effect of the voice, and achieve the effect of clear pronunciation and perfect intonation. Bel canto and vocal music teachers in colleges and universities should follow the principles of bel canto singing, adopt traditional bel canto training methods, and effectively train students in bel canto images and resonance positions. On this basis, they should skillfully place Chinese characters to ensure the purity of the singing.

5.3. Incorporate Bel Canto into the Performance of Folk Songs and Pop Songs

Innovation in bel canto and vocal music teaching in colleges and universities should incorporate bel canto singing techniques into the performance of folk songs and popular songs. Bel canto and vocal music teachers in colleges and universities should actively integrate bel canto and vocal music into the performance of ethnic songs and popular songs. Through bel canto and vocal music, they should provide technical support for the performance of ethnic songs and popular songs, while retaining the artistic style characteristics of ethnic songs and popular songs, to achieve a perfect integration of bel canto and the performance of ethnic songs and popular songs. In colleges and universities, bel canto and vocal music teachers should actively seek breakthroughs in timbre and high-pitched techniques in the integration of bel canto with ethnic songs and popular songs, and fully carry forward the charm of ethnic songs and popular songs.

5.4. Carry out Diverse Bel Canto Art Practices

Innovation in bel canto and vocal music teaching in colleges and universities should actively carry out diverse bel canto art practices. Bel canto and vocal music teaching in colleges and universities should not confine students to practice in the piano room. Instead, it is necessary to actively explore practical channels for bel canto and vocal music art, provide students with diverse opportunities for bel canto art practice, and enhance their practical experience in bel canto art and stage singing ability. Through diverse bel canto art practices, students' accurate mastery of bel canto singing techniques can be enhanced.

6. Conclusion

In this paper, a new scheme based on GAN key generation is proposed, and a plaintext related image encryption algorithm is designed according to the generated GAN key pool. Learning chaotic random keys of GAN-DNADE using GANs. The main conclusions are as follows:

1. The scheme in this paper trains and generates GAN key pool, which not only has the advantage of chaotic random key, but also has the feature of non-repeatability, which greatly improves the key generation speed and increases the security of the encryption system.
2. The random phase mask used in the algorithm based on GAN key pool is related to plaintext, so it can resist the attacks of known plaintext and selected plaintext.
3. The encryption scheme proposed in this paper can effectively improve the nonlinear characteristics of low-light level image encryption through chaotic system, so that the encryption scheme can effectively cope with various statistical analysis.
4. The key generation method is not only suitable for the image encryption algorithm proposed in this paper, but also can be applied to other encryption schemes.

7. Conflict of Interest

The authors declare that there are no conflict of interests, we do not have any possible conflicts of interest.

Acknowledgments. None.

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