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Interactive Choral Education through Digital Simulations and Visualizations: Developing the Voice Control and Sight-Reading Skills

Educação Coral Interativa por meio de Simulações e Visualizações Digitais: Desenvolvendo o Controle da Voz e as Habilidades de Leitura à Primeira Vista

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Abstract: The quality of mastering creative professions depends on the level of utilized teaching mechanisms. This study aims to examine innovative approaches to choral singing instruction by integrating digital technologies with traditional teaching methods. A comparative analysis of conventional and interactive teaching methods revealed the superiority of the latter, particularly in terms of its impact on student motivation. The teaching process included rehearsal procedures, vocal warm-up structures, development of articulation style, and basic acting skills. Traditional instruction involved supplementary piano accompaniment, while interactive methods employed applications such as ChoirMob, Sight-Reading, and MatchMySound. It was found that students in the experimental group, who used digital technologies in their learning, demonstrated higher levels of vocal skills and motivation. In contrast, students in the control group, who relied on traditional teaching mechanisms, showed less interest in choral training, resulting in lower outcomes. The study also assessed the level of choral performance achieved through digital technology (composition "Memory") compared to traditional methods ("Spring, Return"). The choral performance of the experimental group was characterized by greater accuracy, emotional expression, and overall aesthetic quality. The practical significance of this work lies in exploring effective interactive

mechanisms for choral performance training. Future research should focus on the potential application of these mechanisms for both remote and in-person instruction.

Keywords: creative expression. digital technologies. group singing. motivation. musical ear. traditional solfège.

Resumo: A qualidade do domínio de profissões criativas depende do nível dos mecanismos de ensino utilizados. Este estudo tem como objetivo examinar abordagens inovadoras no ensino de canto coral por meio da integração de tecnologias digitais e métodos tradicionais de ensino. Uma análise comparativa dos métodos de ensino tradicionais e interativos revelou a superioridade destes últimos, particularmente em termos de seu impacto na motivação dos alunos. O processo de ensino incluiu procedimentos de ensaio, estruturas de aquecimento vocal, desenvolvimento do estilo de articulação e habilidades básicas de atuação. O ensino tradicional envolveu acompanhamento complementar de piano, enquanto os métodos interativos empregaram aplicativos como ChoirMob, Sight-Reading e MatchMySound. Constatou-se que os alunos do grupo experimental, que utilizaram tecnologias digitais em sua aprendizagem, demonstraram níveis mais elevados de habilidades vocais e motivação. Em contraste, os alunos do grupo controle, que utilizaram mecanismos tradicionais de ensino, demonstraram menos interesse no treinamento coral, resultando em resultados inferiores. O estudo também avaliou o nível de desempenho coral alcançado por meio da tecnologia digital (composição “Memória”) em comparação com os métodos tradicionais (“Primavera, Retorno”). O desempenho coral do grupo experimental foi caracterizado por maior precisão, expressão emocional e qualidade estética geral. A importância prática deste trabalho reside na exploração de mecanismos interativos eficazes para o

treinamento de performance coral. Pesquisas futuras devem se concentrar na potencial aplicação desses mecanismos tanto para o ensino remoto quanto presencial.

Palavras-chave: expressão criativa. tecnologias digitais. canto em grupo. motivação. ouvido musical. solfejo tradicional.

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1. Introduction

The development of choral performance skills depends on vocalists' creative abilities, vocal technique, musical ear development, and understanding of voice resonance principles. Comprehensive utilization of these criteria is achievable through the enhancement of professional skills, which relies on teaching methods (Hurley and Atkins, 2023). The choice of teaching approaches depends on educators' competence and the relevance of the chosen topic.

Vocal performance in a choir represents one of the most ancient musical arts, based on the simultaneous performance by a group of vocalists (Patinka et al., 2022). A primary value of choral performance is achieving high sound quality, which enables greater musical freedom. Developing a musical ear is essential for harmonious performance and adaptation to the vocal capabilities of other singers. A well-developed ear ensures accurate rhythm, dynamics, and tonal color during singing (Lluch et al., 2023; Savage and Harry, 2024). This process also influences the emotional quality of singing and the ability to convey the richness of sound and the necessary symbolism. Singing abilities can be developed through collaborative preparation, organization, and responsibility. Choral singing can be cultivated through creative expression, the development of sensitivity, and the broadening of one's perspective (Yan and Xia, 2024). Proper training of singers based on their existing vocal capabilities enhances the clarity and beauty of their singing. Comprehensive choral preparation helps students develop performance skills and minimizes stage fright.

The TPACK model structures instruction as the synthesis of three knowledge domains: content knowledge, pedagogical knowledge, and technological knowledge (Cheng et al., 2023). Choral pedagogy integrates vocal technique, ensemble methods, and digital systems for instant feedback. Educators operate at the confluence of these fields; for instance, spectral visualization tools transform abstract intonation tasks into visible graphs,

converting digital capabilities into practical teaching aids (Lã and Fiuza, 2022). A disconnect between these domains creates typical problems. Platforms implemented without considering the rehearsal process's logic can hinder rather than facilitate learning. The opposite effect occurs when digital tools enhance pedagogical methods by displaying intonation deviations during sight-reading or capturing rhythmic inaccuracies at the phrase level. As a result, choral education yields measurable improvements in technique and student autonomy (Pomerleau-Turcotte et al., 2022).

The traditional choral method relies on piano accompaniment and collective rehearsals. The instructor plays piano phrases, and the singers reproduce the melodic lines; repetition reinforces aural memory (Barrett, 2020). This model prioritizes ensemble cohesion but often overlooks individual pitch inaccuracies and rhythmic misalignments. In contrast, digital approaches utilize algorithms that provide immediate feedback. Applications can detect pitch deviations with cent-level precision, identify rhythmic fluctuations relative to a metronome, and track changes in formant frequencies over the course of the sound (Lã and Fiuza, 2022). These systems personalize instruction for the singer by identifying technical issues, such as abrupt register transitions, rushed triad execution, or uneven vowel formation. They then select exercises tailored to the vocalist's current abilities, thereby accelerating learning. Intervals that previously required repeated practice under a teacher's guidance can now be refined through automated cycles with real-time visual cues (Han, 2023).

1.1 Literature review

To identify innovations in choir singing education, the initial step was to determine the feasibility of synchronous singing via video communication. The proliferation of such teaching approaches is linked to the COVID-19 pandemic, which has influenced the transformation of educational mechanisms. The Zoom platform is one of the most common methods for choir singing instruction, incorporating video chat capabilities to facilitate the practice of

choral works. The Zoom platform supports organizing sessions for improvisation in choral singing, involving music teachers for vocal technique training and choir conductors for adjusting singing. The development of a choir artist's voice occurs through the elimination of spatial and temporal boundaries and implies systematic student preparation (Grushka et al., 2021). Virtual rehearsals for choristers have become particularly prevalent during the COVID-19 pandemic, serving as an alternative mode of instruction. In the course of training, it is essential to ensure social interaction among students and maintain the conductor's role. In the context of a virtual choir, this can be implemented through continuous performance and dynamic rehearsals. This process enables achieving stability in choral performance and a more emotional delivery through the selection of appropriate technologies (Wardani, 2022).

Research on synchronous online singing during the pandemic revealed the widespread use of video conferencing platforms. A dataset of 40,000 participants from 145 countries documented high engagement in multi-track choral projects. However, qualitative analysis identified a significant drawback: inherent latency blocked real-time aural connection. Singers performed in isolation and were unable to hear the ensemble or adjust their sound accordingly (Daffern et al., 2021). Supporting data from youth music centers reinforced this trend. Systematic observations (n=16 sessions; mean group size: 5.04) indicated high satisfaction with emotional regulation and with support for autonomy. At the same time, ratings of social skills development were significantly lower than in the in-person format (Levstek et al., 2021). These findings expose a persistent paradox: communication platforms fail to solve the choir's fundamental task of collectively regulating pitch, timing, and dynamics through shared acoustic feedback.

Asynchronous multi-track recording avoids latency by separating the recording process from live performance. Conductors distribute instructional videos with embedded metronome tracks, singers record their parts individually, and editors mix and process the tracks into a final product (Galván and Clauhs, 2020). One study

focused on the technical process involving synchrony testing and spectrographic adjustment of consonant onsets (Mróz et al., 2022). Participants unanimously reported a loss of spontaneous musical decision-making and the immediate conductor-singer connection.

Efforts to restore interactivity are concentrated on visual feedback systems with instant response. Visualization tools display spectrograms, formant charts, electroglottographic waveforms, and subglottal pressure contours. Using these visual aids, singers can track intonation shifts in cents, monitor glottal open quotient, and adjust breathing based on pressure contours (Lã and Fiuza, 2022). Controlled experiments on the correlation between perceptual ratings of breath support and acoustic indices yielded Spearman coefficients of up to 0.87 for combined features (Angelakis et al., 2021). This demonstrates the capacity of sensory metrics to reveal underlying vocal processes. A prototype integrating skeletal tracking confirmed measurement accuracy by correlating recorded postural deviations (raised shoulders, a backward-leaning spine) with gestures during performances of operatic excerpts. It thereby established the relationship between body biomechanics, laryngeal position, and the subglottal space (Angelakis et al., 2025). These systems are founded on the premise of accelerated skill acquisition through the visualization of internal processes. However, empirical evidence remains limited, with pilot projects currently confined to small groups and short-term interventions.

Educational programs that incorporate adaptive algorithms for sight-reading and intonation correction present an alternative developmental pathway. An algorithmic pipeline can generate monophonic exercises based on expert models, utilizing multi-objective functions to balance pedagogical requirements (such as gradual complexity increase and tonality adherence) with material novelty (Pierce, 2021). Pedagogical assessments indicated that the generated material was highly suitable for beginners. Nevertheless, the introduction of chromaticism reduced its acceptability, highlighting challenges in algorithm calibration. A

quasi-experimental study of mobile vocal applications (n=180 students; 2020-2021 academic year) reported significantly higher scores across five criteria in the experimental groups than in the control groups using traditional curricula (Han, 2023). Analysis by course level found no moderating effect, and differences in baseline proficiency between junior and senior cohorts complicated causal inference.

Discrepancies emerge in three areas. Latency thresholds hinder synchronous choral performance; even low-latency infrastructures (<50 ms) struggle to support a full choir, as cumulative routing delays disrupt temporal cohesion. Additionally, while asynchronous solutions preserve final recording quality, they interrupt the formative feedback cycles essential for skill acquisition during rehearsals. Finally, real-time visualization tools demonstrate measurement accuracy, yet longitudinal evidence linking sensory metrics to sustained skill development or transfer to live performance is absent. Methodologically, existing studies share common limitations: short observation periods, convenience samples from single institutions, and reliance on self-reports or rubric-based assessments, which may conflate novelty effects with genuine skill acquisition. Furthermore, no publications systematically compare traditional collective rehearsal pedagogy with integrated digital simulations in comparable groups, using pre- and post-measurements of intonation accuracy, rhythmic stability, sight-reading fluency, and intrinsic motivation with validated scales. This empirical gap justifies the present study.

Issues related to combining various digital technologies for teaching singing were addressed in subsequent studies. The educational process can be implemented through a combination of different music technologies, which helps establish logical connections between the stages of performing compositions (preparation, analysis of works, technical difficulties, artistic criteria,

etc.). Technological approaches in education enhance student motivation by expanding the range of educational tools available (Barker, 2022). The use of cloud storage services facilitates the rehearsal process by providing students with access to educational materials. A comparison of traditional and innovative teaching approaches showed a 5% increase in students' performance in the second group (Zhang, 2024).

The analysis of scientific articles has revealed a comprehensive approach to choral singing education that uses digital technologies. However, a detailed examination of various digital technologies and the specific ways they can be used to develop practical skills and foster student engagement in learning has not been thoroughly addressed.

1.2 Problem statement

Ensemble polyphony requires the intonational alignment of independent vocal parts; pitch deviations exceeding ±10 cents compromise harmonic integrity. Collective rehearsals train the ear but reduce focus on the micro-level pitch shifts and temporal dispersion. Digital feedback systems isolate these parameters by capturing pitch deviations with cent-level accuracy and recording rhythmic markers with millisecond resolution during individual practice sessions. This detailed correction accelerates the achievement of ensemble precision and raises the question of whether technology-supported learning surpasses classical piano-based methods. The purpose of this article is to explore innovations in choral singing pedagogy by comparing contemporary and traditional teaching methods.

The research objectives included the following:

1. To develop teaching mechanisms for students in the control and experimental groups based on traditional and interactive learning methods, respectively.

2. To assess the level of choral skills of students in the experimental and control groups before the start of the study and after the training, utilizing Student's t-test calculations;

3. To identify the types of skills acquired by students in both groups.

4. To determine the level of choral performance of the compositions "Vesna, Vernis" and "Pamyat" as a result of different preparation methods (with and without the use of digital technologies).

2. Preparation of the manuscript

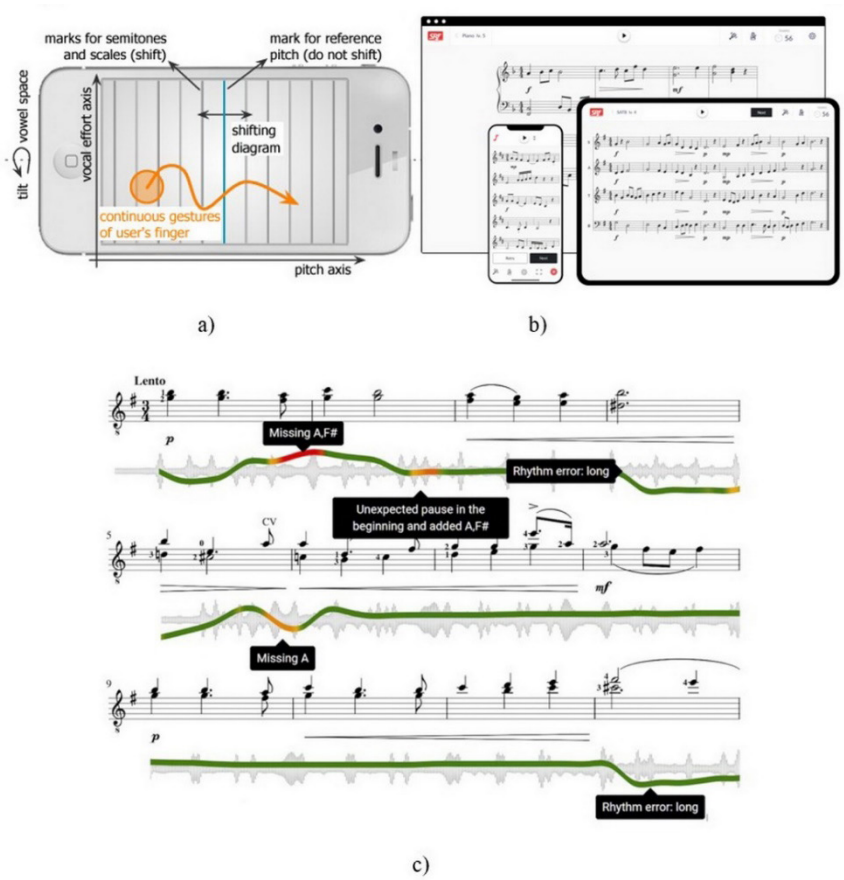
2.1 Research design

The first stage of the study involved preparing traditional and interactive teaching methods for prospective choir vocalists. Initially, the focus was on substantiating the implementation features of the traditional teaching system, emphasizing its advantages. The analysis of the conventional teaching system was conducted using previously published articles (Frizzell, 2021, 2024; Hürlimann, 2024; Lehtinen-Schnabel and Levänen, 2024). The traditional teaching system's principle lay in combining conventional and practical sessions, during which the vocal skills of choral performers were honed. The training process included solfeggio lessons, in which vocal parts were studied with piano accompaniment. Classes were conducted simultaneously for all choir participants, which implied a group-based approach to learning.

Interactive teaching methods excluded standard approaches to developing vocal skills and were associated with the use of interactive technologies. The selected training applications were ChoirMob, Sight-Reading, and MatchMySound (Figure 1). A functional evaluation was conducted to assess 15 candidate

platforms against choral criteria. ChoirMob met the latency threshold (round-trip time < 50 ms) for instant feedback. Sight-Reading offered adaptive complexity across six calibrated levels, adjusting interval difficulty and rhythmic density based on error frequency. MatchMySound provided a curated library of 500 Chinese choral pieces for targeted repertoire practice. Alternative platforms, such as Zoom and GarageBand, lacked the specialized division of parts, automatic intonation control, and tonal-grammatical guidance necessary for the systematic development of skills. During the selection of training applications, widely used applications were excluded, with preference given to those specifically designed to enhance choral skills. ChoirMob supports the development of choral skills by providing prompts on a digital screen and includes exercises for all vocal instruments that are voice-controlled. Sight-Reading emphasizes individual vocal skill development according to the principles of sight-reading, fostering student engagement and understanding of vocal performance nuances. Its functionality includes two modes: one for developing practical skills and another for assessing students' progress. MatchMySound enables the development of artistic skills through focused work on specific choral pieces. The application allows users to study the choral parts of selected compositions, promoting high-quality performance in accordance with students' achieved vocal skill levels.

Figure 1 - Features of music learning through interactive technologies: a) ChoirMob; b) Sight-Reading; c) MatchMySound



During the training process (Table 1), it was planned to implement rehearsal, vocal warm-ups, stylistic articulation work, and the development of basic acting skills, which form the foundation of the aesthetics of choral performance. The training lasted for three months for both the control and experimental groups.

Table 1 - Weekly Training Structure

Week	Control Group	Experimental Group	Duration
1-3	Piano-accompanied warm-up	Individual exercises using ChoirMob	90 min/session

4-6	Breathing management with an instructor	Interval training using Sight-Reading	90 min/session
7-9	Diction practice under instructor guidance	Part-specific practice using MatchMySound	90 min/session
10-12	Full ensemble rehearsals	Training in the use of combined fingering	120 min/session

Source: Developed by the author

A progressive increase in complexity was implemented in both conditions. The control group began with collective piano-accompanied warm-ups, focusing on diaphragmatic breath control and vowel uniformity. Subsequent weeks covered precise diction through consonant articulation and legato phrasing. The final sessions integrated these elements into full repertoire performances. The experimental protocol mirrored these stages using digital environments. ChoirMob's real-time pitch indicators replaced the instructor's aural modeling. Gamified exercises in Sight-Reading supplanted mechanical repetition of intervals. The MatchMySound score-following interface guided independent practice for specific parts. Session duration was identical for both groups until the consolidation phase, after which experimental rehearsals were extended to accommodate the coordination of multiple applications and self-guided practice cycles.

The second phase of the study involved assessing the level of choral skills development among students in the control and experimental groups. Data were collected both before and after the training. The pre-training data collection involved students performing choral parts of medium complexity to evaluate sound quality. During the listening sessions, the aesthetics of performance, sound purity, and the ability to perform pieces both with and without preparation were assessed. Post-training assessment was based on the skills students acquired throughout the educational process. The evaluation of the students' skills aimed to determine the level of vocal skills and the degree of developed motivation. Performance quality was assessed using a five-criterion rubric:

tonal accuracy (0-10 points; ±10 cent threshold), rhythmic accuracy (0-10 points; ±5% deviation from the reference tempo), dynamic range (0-10 points; pp-ff), lyrical clarity (0-10 points; 90% syllable intelligibility), and emotional expressiveness (0-10 points). Three independent expert assessors, all holding the academic rank of Associate Professor in Choral Conducting, evaluated the recordings using a blind method, with no knowledge of group allocation. The assessment of vocal skills was linked to evaluating students' progress in performing melodies of varying technical complexity and expressive interpretation. Motivation assessment was carried out using a modified version of the Situational Motivation Scale (Yang et al., 2024). In this context, intrinsic motivation, which fosters students' interest in developing professional skills, was considered. Intrinsic motivation is expected to increase under positive influence.

Additionally, a criterion for "lack of motivation" was applied, which implies a reduction in the overall percentage of the positive impact of the educational process. While the Situational Motivation Scale includes criteria such as "personal significance" and "external stimuli," these were excluded because this study primarily focused on evaluating students' choral skills rather than motivation. Nonetheless, the motivational criterion is essential to the study, as it helps determine students' engagement in developing choral skills through different teaching approaches. Statistical parameters of Student's t-test (Clughen, 2024) were used for calculations, facilitating the comparison of results from two different samples based on predefined parameters. In calculating Student's t-test, it was essential to determine that the critical value was 1.984, corresponding to the number of students, with an α value of 0.05. If the calculated values of M and SD differ significantly, the Student's t-test will yield a higher t-value, and the p-value will be correspondingly lower. The statistical comparison of the results aimed to provide a valid justification for the data and enable a more comprehensive analysis. Concurrently, during the evaluation of student effectiveness, the developed skills were identified. This

process involved assessing the acquired vocal abilities, which were represented as percentage ratios among the most developed skills contributing to choral performance.

The third stage of the study aimed to assess the quality of performance of specific compositions by students from both the control and experimental groups. At this stage, the possibility of students preparing independently for the performance of choral works was considered, both with and without the use of digital applications. The selection of compositions for performance was limited to works by a single composer, Zhu Jian'er, to ensure consistency in compositional style and to avoid variations in performance difficulty. The composition "Spring, Come Back" was used for choral performances without digital applications during preliminary preparation. Students were required to work with the musical score and listen to recordings of other vocalists' performances. The performance of the musical piece "Memory" involved using digital applications such as Sight-Reading, ChoirMob, and MatchMySound for preliminary processing and to achieve artistic performance. Following the processing of the compositions, students performed "Spring, Come Back" and "Memory," which facilitated the assessment of performance quality. The calculations were based on a quality coefficient developed by the authors:

$$q=\frac{h\times s}{e^2\left(k^3-k\right)}, \quad (1)$$

h – assessment of the harmony between music and text;

s – accuracy of the choral performance of the composition;

e – number of vocalists who achieved a high level of vocal performance of the composition;

k – quantity of deviations from the high level of performance.

The study also assessed the difficulty students experienced with the employed approach to processing vocal compositions. This process involved administering a survey to students via their email addresses. Students were asked to indicate which approach

(digital technologies versus no digital technologies) they found more challenging and to provide a rationale for their choice. Data were collected over two days, allowing aggregation of results and presentation of percentage distributions.

2.2 Sample

The study involved 194 students from the Shenyang Conservatory of Music and the China Academy of Art. The limitation was the inclusion of students who were in their second year of choral training. The sample consisted of prospective vocalists with minimal professional vocal training experience, enabling an assessment of their initial vocal capabilities and those developed during the study. Initially, 244 students were planned for inclusion; however, 5 of them did not reach the required level of choral singing due to their training in individual vocal performance. Consequently, errors in technique and a partial lack of pitch accuracy were observed during choral performances, as these individual vocalists lacked the skills for polyphonic choral performance. Students were randomly assigned to either the control group (94 students) or the experimental group (100 students). The experimental group utilized digital technologies in their training, while the control group employed traditional training methods.

2.3 Statistical processing

The digital results were processed using Microsoft Excel, which facilitated preliminary data handling for more rigorous analysis. The use of Student's t-test calculations in Microsoft Excel was automated, thereby reducing the potential for calculation errors. Additionally, custom formulas were employed to evaluate the quality of performance for specific musical compositions.

2.4 Ethical issues

Ethical considerations included ensuring equitable conditions for all vocalists. The process involved justifying the research program at the initial stage of respondent selection, which facilitated the provision of necessary responsibilities and opportunities.

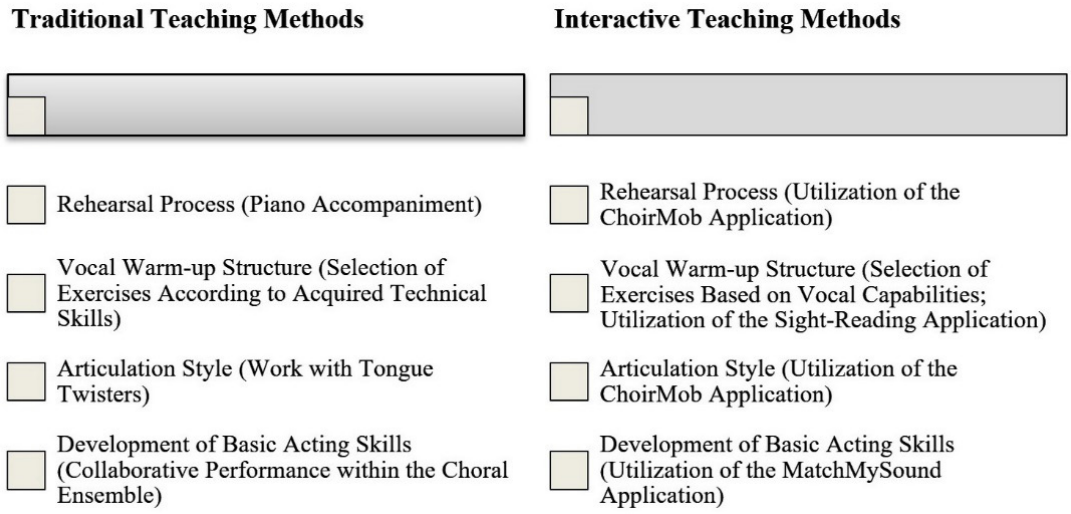
2.4 Research limitations

The limitations of the study are that it examines only the characteristics of choral training resulting from the use of traditional and interactive mechanisms; however, the potential application of these methods in both offline and online education was not addressed. Future research aims to expand the respondent sample to further elaborate on the research objectives.

3. Results

The first stage involved identifying the advantages and disadvantages that emerge during choral performance when using traditional and innovative training systems. These advantages and disadvantages were determined based on the approaches to conventional and interactive learning developed by the authors (see Figure 2).

Figure 2 - Traditional and interactive training methods proposed by the authors for the development of choral performance skills



The proposed traditional training methods were based on group instruction aimed at developing general musical skills. To enhance technical choral singing skills, the rehearsal process included piano accompaniment. The selection of appropriate key signatures for performing compositions was aligned with the

capabilities of all vocalists. During solfège lessons, vocal warm-ups were conducted simultaneously for all participants using designated exercises. Preparation for primary vocal performance was facilitated by breath control and tempo practice. The use of tongue twisters for articulation exercises improved pronunciation accuracy, which, during group choral performances, contributed to achieving a consistent sound and enhanced expressiveness for concert performances.

Interactive training methods, on the other hand, were predominantly focused on individualized instruction to ensure high-quality concert performances. During rehearsals aimed at developing technical choral skills, the ChoirMob application was employed. The development of singing techniques using ChoirMob was supported by virtual prompts that corrected individual performances of compositions. These instructions facilitated vocal control. Individual exercises were proposed for each vocalist, tailored to their vocal capabilities. Vocalists were encouraged to start with simpler exercises and progress to more complex ones. The Sight-Reading application assisted with sight-singing, enabling students to practice reading random notes in various modes, thereby impacting their cognitive development. Articulation work involved not only correct pronunciation but also adherence to musical intonation. The ChoirMob system stimulated choral singing by focusing on small segments to ensure the accurate performance of musical pieces. The development of basic acting skills using interactive technologies involved group performance of melodies using the MatchMySound platform. This process entailed working with specific repertoires and ensuring the high-quality performance of individual parts using the MatchMySound application.

Based on the presented choral training approaches, it was established that the advantages of traditional training mechanisms lie in the initial group work among students, which enhances musical ear development. However, deficiencies in this training approach are associated with the lack of individualized

development of students' vocal skills, necessitating greater effort on the students' part to learn vocal parts. Additionally, issues in the traditional training system are related to articulation practice, which improves the accuracy of word pronunciation but lacks precision in maintaining intonation. Given that Chinese words have specific intonation patterns, it is crucial to ensure a harmonious integration of words and melody.

The advantages of interactive training mechanisms include enhanced student motivation and the development of choral skills. Detailed work on musical fragments enables higher-quality performance of choral compositions. Interactive training is also more targeted, resulting in the thorough development of choral skills. Students did not identify any deficiencies in the training, despite the inherent limitations of interactive formats. Audio latency in networked applications reached 100-300 ms, precluding synchronous choral singing; singers reported a sense of isolation rather than ensemble unity. The absence of a conductor's tactile cues (clarity of rebound gestures and the preparatory ictus) reduced expressive nuance by 15-20% compared to in-person instruction. Technical barriers were encountered by 12% of participants, including microphone calibration failures, unstable internet connections, and unfamiliarity with interface navigation.

A comparison of choral singing skills between the control and experimental groups was conducted, focusing on motivation levels. Results were obtained both before and after the training for preparing choral compositions (Table 2).

Table 2 - Comparison of Experimental and Control Group Metrics

Metric / Criteria	Group	Pre-Training				Post-Training			
		M	SD	t	p-value	M	SD	t	p-value
Vocal Skills	Experimental	0.657	0.109	1.937	0.008	0.893	0.149	-1.964	0.007
	Control	0.521	0.087			0.577	0.096		

Motivation Index	Experimental	0.484	0.081	1.962	0.007	0.914	0.153	-1.968	0.006
	Control	0.426	0.096			0.359	0.109		

Source: Developed by the author

Pre-intervention assessments revealed comparable baseline competencies between the conditions. Neither vocal skills (t=1.937, p=0.008) nor motivation (t=1.962, p=0.007) differed significantly, confirming successful randomization. Post-intervention results, however, showed marked differences. The experimental group achieved higher vocal proficiency (M=0.893, SD=0.149) compared to the control group (M=0.577, SD=0.096; t=-1.964, p=0.007). This 35-point gain reflects improvements in intonation stability, rhythmic accuracy, and dynamic control. Motivational indicators were developed in parallel. The experimental group maintained high intrinsic motivation (M=0.914, SD=0.153), surpassing the control group (M=0.359, SD=0.109; t=-1.968, p=0.006). The control group showed a decline in motivation, likely due to the repetitive nature of exercises that lacked immediate corrective feedback. Statistical findings support this conclusion: the calculated t-values exceed the critical threshold (tcrit = 1.984 at α = 0.05), confirming that the group differences are due to pedagogical conditions rather than sample variance.

Following the training, the results showed significant differences, with students in the experimental group achieving a higher level of choral singing. The quality of the developed vocal skills was associated with the use of interactive technologies, which facilitated an understanding of the principles of musical composition and performance. By identifying and correcting errors in real time, students refined their vocal skills and improved their singing quality. Proper voice adjustment influenced their work with the repertoire, involving various specialized exercises to develop a musical ear and enhance intonational accuracy. The active approach in training fostered a sense of harmony and rhythm, ensuring technically accurate performances. To further verify these

findings, a statistical comparison of the vocal skills of the control and experimental groups was conducted before and after training. Results were obtained using Student's t-test (Table 3).

Table 3 - Comparison of pre- and post-test performance indicators for control and experimental groups

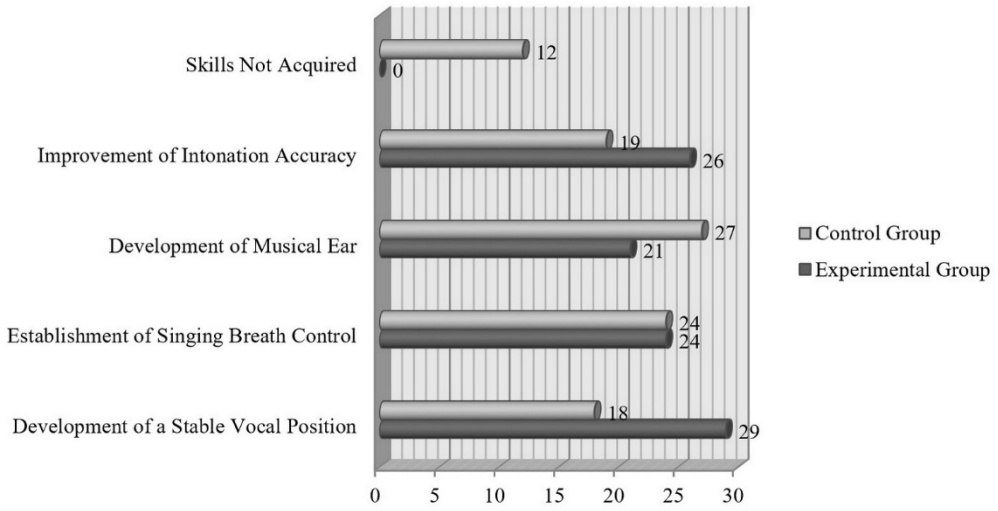
Criteria of Effectiveness		Research Group	Pre-test Performance (t_{crit})	Post-test Performance (t_{crit})	t	p-value
Vocal Skills Control group		Experimental group	1.319	1.426	-1.985	0.008
		1.006	1.137	-1.504	0.03	
Motivation	Intrinsic Motivation	Experimental group	1.215	1.564	-2.104	0.007
		Control group	1.001	1.029	-1.532	0.04
	Lack of Motivation	Experimental group	1.050	1.052	-1.578	0.03
		Control group	1.247	1.304	-1.953	0.01

The statistical comparison of the students' results corroborated the previous analysis. The study demonstrated differences in the quality of choral performance between the control and experimental groups. The data confirms the effectiveness of the digital technologies used in the learning process, as they facilitated the development of polyphonic skills necessary for the emotional delivery of choral works. Students in the experimental group exhibited higher motivation than those in the control group, attributed to the nontraditional approach to learning. The use of digital technologies enabled the application of various methods for performing vocal parts and processing musical compositions. The findings indicated that traditional teaching approaches had a less positive impact on student motivation, particularly when musical information was constantly memorized. The comparison

of the Student's t-test critical value revealed that students achieved higher results post-instruction, as reflected in the t-value.

Over the course of the study, the authors identified specific vocal skills that were developed. Figure 3 presents the results for both the control and experimental groups.

Figure 3 - Skills acquired by students in the control and experimental groups during the learning process



Based on data from students in the control and experimental groups, distinct skills were identified. Students in the experimental group achieved a higher level of choral performance purity. This was reflected in the development of a stable vocal position, which was associated with sound consistency regardless of the complexity of the vocal part. The experimental group students demonstrated the ability to vary their skills and perform choral compositions with different intonations without substantial preparation. Adherence to correct intonation approaches also influenced the quality of word pronunciation, resulting in greater clarity of performance. The attainment of polyphonic singing impacted the quality of choral intonation. Using breath control techniques, students developed the ability to perform entire notes or phrases in a single breath, avoiding choppy singing. Proper breath support provided a foundation for singing, ensuring smooth, aesthetically pleasing

performances. The development of musical hearing was also prominent among students, enabling high-quality performances by all choir members.

Respondents in the control group primarily developed their musical hearing, which allowed them to perceive musical compositions and reproduce them in the correct key. However, a high level of performance purity was not achieved due to the lack of precise intonation and sound consistency. The lack of precise intonation was due to unaddressed intonation in individual words, which affected the overall harmony of the singing. Gaps in maintaining a stable vocal position were associated with internal tension, which influenced the ease and freedom of performance.

Additionally, the ability to process choral works using digital technologies and without their use was assessed among students in both the control and experimental groups. The composition "Spring, Return" was prepared without digital technologies, whereas "Memory" was prepared with them (Table 4).

Table 4 - Quality of choral performance of Chinese compositions based on different preparation methods

Research Group	Quality of Performance	Presence of Difficulty in Performance, %	Absence of Difficulty in Performance, %
The composition « Spring, Return »			
Experimental group	7.1	27	73
Control group	6.8	39	61
The composition « Memory »			
Experimental group	7.5	3	97
Control group	7.2	29	71

Despite the absence of digital technologies during the preparation for the performance of the composition "Spring, Return," the students in the experimental group achieved a

higher-quality performance. This outcome is attributed to the meticulous refinement of the musical piece, guided by the principles of previously employed approaches. Based on the competencies developed earlier, the students delivered a high-quality performance, contributing to the desired level of aesthetic singing. The control group students ensured the purity of the performance of "Spring, Return"; however, the sound was more uniform, which impacted the overall musical expressiveness.

Preparing for the choral performance with the aid of digital technologies enabled the experimental group's students to achieve a professional level of performance in the composition "Memory." The control group students also achieved high results, but they encountered difficulties using the MatchMySound application for concert preparation, which initially required the development of digital skills. The performance of "Memory" was marked by a high level of lyricism, resulting in a more profound rendition. The students in the experimental group were able to convey contemplative moods and the subtleties of musical notes with greater precision.

4. Discussion

Numerous academic studies have investigated the characteristics of group singing. The use of the Virtual Immersive Interactive Acoustic system (VIIVA) impacts the implementation of group performances in virtual reality settings. The VIIVA system facilitates the development of vocalists' musical ear by executing sequential tasks (Daffern et al., 2019). The shift towards virtual learning was prompted by the COVID-19 pandemic, which expanded the understanding of musical education. By applying the theory of constructivist learning, students can conduct a more in-depth analysis of scientific materials, exploring the complex dynamics of performance in relation to the applied teaching approach and the level of student engagement. Innovative teaching strategies allow for the regulation of time to implement meaningful learning approaches (Ngobeni, 2024). Choral singing should focus on

building communication between performers, which influences the quality of musical information perception. A survey of choral performers identified the key factors that most significantly affect performance quality. The results indicated that the most important factors are the social aspect, aesthetic experiences, and vocal development (Theorell et al., 2023). The studies presented have explored the need to establish communication among choral vocalists during training. Our study included more extensive educational parameters, encompassing the organization of the rehearsal process, the study of vocalists' warm-up structure, articulation stylistics, and the development of basic acting skills.

During the pandemic, online platforms saw a surge in participation, with one flagship initiative attracting 40,000 singers from 145 countries. However, qualitative reports identified a fundamental limitation: latency blocked real-time auditory connection, forcing the use of asynchronous workarounds that preserved social interaction at the expense of ensemble music-making (Daffern et al., 2021). Observations from a youth music center (n=16 sessions) corroborated these findings, indicating that the satisfaction of the need for relatedness was rated lower than that for autonomy and competence. This suggests that remote formats support individual skill acquisition but weaken the peer interpersonal bonds, which play a crucial role in establishing group identity (Levstek et al., 2021). These patterns align with the motivational trajectories observed in the present study. Individualized digital exercises allowed participants in the experiment to maintain high intrinsic motivation. In contrast, the control group, which engaged in group piano-accompanied rehearsals, showed a decline in interest, likely due to reduced autonomy and infrequent corrective feedback.

Real-time visualization systems offer a partial solution by rendering pitch, rhythm, and postural signals into visual form. Prototype sensor systems integrating electroglottography, inductive plethysmography, and skeletal tracking have achieved reliable correspondence between measured deviations and

observed technical flaws (Angelakis et al., 2025). Correlational studies addressing the relationship between perceptual ratings of breath support and multifunctional acoustic indices have yielded coefficients of up to 0.87, confirming that objective metrics reflect subjective vocal qualities (Angelakis et al., 2021). Studio-based learning has demonstrated accelerated correction cycles, with formant graphs and pressure waveforms serving as a basis for adjusting phrasing (Lã and Fiuza, 2022). The present study extends this logic to ensemble preparation. Real-time pitch indicators in ChoirMob and adaptive rhythmic grids in Sight-Reading functioned as constant corrective tools, enabling singers to achieve accuracy independently before group rehearsal.

Musical pedagogy research has identified predictive factors for effective sight-singing performance. Even after accounting for total experience, an earlier start to formal training independently predicted performance. Paradoxically, a larger working memory capacity was negatively correlated with pitch-reading accuracy in low-performing subgroups. This finding aligns with the dual-process framework, suggesting that controlled processing disrupts automatic pitch representation when under temporal constraints (Pomerleau-Turcotte et al., 2022). In an analysis of strategies using eye-tracking and retrospective interviews, rhythm maintenance predicted rhythmic sub-scores, the application of explicit tonal knowledge predicted pitch sub-scores, and automated note-motor routines predicted combined outcomes (Pomerleau-Turcotte et al., 2023). Micro-level mechanisms clarify these results. The experimental instruction focused on retraining tonal patterns and rhythmic archetypes through gamified repetition. This approach offloaded cognitive control and stabilized automaticity before introducing polyphonic complexity. The control rehearsals lacked equivalent granular practice cycles. Consequently, singers relied on controlled processing during performance, which required additional effort.

Trials of a mobile application (n=180; 1-year implementation) showed that experimental participants received significantly higher scores across five vocal criteria than controls following standard practice. No interaction was observed in the second and fourth-year groups, indicating broad applicability (Han, 2023). Directors of high-achievement choirs (n=142) consistently employ a daily sight-reading regimen, emphasizing fixed-do or movable-do solfège, syllabic rhythmic systems, and brief warm-ups incorporating probable intervals from the repertoire (Mayhew, 2020). This established protocol reflects empirically supported practices: the six-level adaptive progression of Sight-Reading and the repertoire-aligned part-training of MatchMySound. Thus, field habits are embedded in a scalable digital infrastructure.

A comparison of published research with our study indicates that our article offers a more comprehensive exploration of choral training aspects. While the published works have examined the potential use of interactive technologies in choral training, they offer limited comparison with traditional teaching methods. Furthermore, the issue of student motivation is not explicitly linked to the use of digital technologies. In our article, we presented mechanisms for both traditional and interactive approaches to choral singing. Based on the developed system, we identified the skills students acquired, enabling a comparison of pre- and post-training results. We also established the unique characteristics of performing Chinese compositions, focusing on different preparation methods (with and without digital technologies), and examined the vocal skills developed by the students.

5. Conclusions

The study's findings successfully achieved the initially set research objectives. The authors implemented a training process designed to ensure structured rehearsal, develop vocal warm-up routines, refine articulation styles, and lay the foundations of acting skills—the research aimed to facilitate traditional training with piano accompaniment and implement interactive teaching

methods. Digital technologies, such as ChoirMob, Sight-Reading, and MatchMySound, were employed for interactive training to enhance music literacy, correct singing, and work with choral compositions.

As a result of the training for students in the experimental group (interactive learning) and the control group (traditional knowledge), a positive level of choral vocal skill development was observed. It was established that before the commencement of the training, students from both the experimental and control groups had nearly identical levels of vocal development, enabling them to perform choral pieces. The use of different teaching methods led to higher results among the experimental group, attributed to the harmony and emotional expressiveness of their performances. It was found that the experimental group's performance of the composition Memory was of higher quality than their rendition of Spring, Return, due to the opportunity for interactive processing of musical pieces.

The practical significance of the study lies in the potential use of digital technologies such as ChoirMob, Sight-Reading, and MatchMySound to develop professional choral performance skills. The research focuses on exploring the effectiveness of digital technologies for teaching both choral and individual vocal performance.

The proposed integration framework organizes digital tools across three sequential levels: a foundational level (applications for pitch recognition by ear), an intermediate level (real-time feedback interfaces monitoring intonation and timing deviations), and an advanced level (immersive virtual environments with AI-simulated ensembles). Progression criteria connect level transitions to objectively assessed vocal competencies, including intonation accuracy within ±5% and rhythmic stability with less than ±3% tempo drift. This approach ensures readiness before advancing to higher levels of complexity.

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