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The Constructive Logic and Empirical Exploration of the Professional Development Support System for University Music Teachers from the Perspective of Digital Intelligence Technology Empowerment

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Abstract

Against the backdrop of the deepening advancement of educational digital transformation, the professional development of university music teachers faces the dual challenges of digital intelligence technology innovation and the unique characteristics of arts education. From the perspective of digital intelligence technology empowerment, and grounded in the TPACK framework, self-efficacy theory, and professional learning community theory, this study constructs a theoretical framework for a professional development support system for university music teachers encompassing four dimensions: Digital Infrastructure Support (DIS), Professional Learning Community Support (PLCS), Administrative Policy Support (APS), and Technical Skills Training Support (TSTS). Using Digital Teaching Efficacy (DTE) as a mediating variable and Professional Development Outcomes (PDO) as the dependent variable, a large-scale questionnaire survey was conducted among 487 in-service music teachers across 52 universities in 15 provinces. Quantitative analysis was performed using Structural Equation Modeling (SEM) and Bootstrap mediation testing. The results indicate that: (1) all four dimensions of support factors have significant positive predictive effects on professional development outcomes; (2) digital teaching efficacy plays a significant partial mediating role between the support system and professional development outcomes, with a mediation proportion of approximately 35%; (3) technical skills training support exhibits the strongest predictive power, followed by professional learning community support; and (4) institution type significantly moderates the path from technical skills training support to digital teaching efficacy. Based on these empirical findings, this study proposes a “three-level, four-dimension, dual-drive” framework for constructing a professional development support system for university music teachers, and outlines specific practical pathways across the four dimensions of infrastructure construction, community cultivation, policy optimization, and full-chain training, aiming to provide a reference for promoting the high-quality development of university music education in the digital intelligence era.

Keywords: Digital Intelligence Technology, University Music Teachers, Professional Development Support System, Digital Teaching Efficacy, Structural Equation Modeling

Introduction

As we enter the third decade of the 21st century, the rapid development of digital intelligence technologies—such as artificial intelligence, big data, cloud computing, and virtual reality—is profoundly reshaping the educational ecosystem, driving the education system towards an evolutionary leap from informatization to digitalization and intelligentization.This technological wave is not merely an incremental improvement but a catalyst for fundamental change, compelling educational institutions worldwide to reconsider traditional paradigms. Zhu and Hu (2022) pointed out that educational digital transformation is no longer merely a change in technological means, but a systemic transformation of educational philosophies, models, and governance, with its core lying in leveraging digital technologies to empower high-quality educational development. Against this macro backdrop, music teachers, as the primary agents of university music education, face profound contemporary questions regarding their professional development models and pathways: when artificial intelligence can assist in music composition and intelligent systems can provide personalized assessments of students' performance, how can university music teachers achieve continuous professional advancement? How should the external support system that underpins this professional advancement be systematically constructed?

Examining the situation from a practical perspective, the dilemmas faced by university music teachers in their professional development exhibit multi-dimensional complexity. First, there is a structural imbalance in digital literacy. Chen's (2022) survey study on music teachers at local normal universities revealed that music teachers generally present a structural imbalance characterized by "acceptable technical operation skills but significantly insufficient skills in integrating technology into teaching." A considerable number of teachers remain at the superficial level of using information technology as an auxiliary presentation tool, failing to achieve deep integration between technology and music education content. Second, the professional development support system is inadequate. Through surveys and interviews, Zhang (2020) pointed out that existing training for university music teachers' information-based teaching competence is generally fragmented, one-way, and lacks sustained follow-up. The systematic nature and targeted focus of specialized training are severely lacking, and the gap between training and teaching practice is prominent. Third, the unique characteristics of arts disciplines exert a significant constraining effect. Unlike teachers in science, engineering, or humanities, the professional development of university music teachers not only requires a deep foundation in artistic practice but also demands the timely acquisition of new skills such as digital music technology, audio production, virtual instrument applications, and online teaching systems. The complexity of their professional development demands is far higher than that of other disciplines. Fourth, the construction of professional learning communities focused on digital teaching practice lags notably. While relatively mature academic communities in music departments have been established around artistic creation and academic research, professional learning communities specifically dedicated to improving digital teaching practice are still in their infancy. Mechanisms for sharing digital teaching experiences across institutions and regions have yet to be systematically established. These intertwined dilemmas highlight a critical gap: while the necessity for digital transformation in music education is widely acknowledged, the systematic support structures required to facilitate this transformation for university music teachers remain underdeveloped and undertheorized.

From the perspective of academic research, the current research landscape reveals a clear structural gap. Existing research on teacher professional development support has largely focused on primary and secondary school teachers or university teachers in science and engineering, with relatively scarce research targeting the specific group of university music teachers. Furthermore, existing research on music teacher professional development tends to emphasize macro-level policy analysis and experience-based recommendations, while empirical research using quantitative methods to deeply uncover the internal mechanisms of the support system within the context of digital intelligence empowerment is extremely rare. Yu (2020) noted that in the age of artificial intelligence, the support system for teacher professional development needs to shift from singular knowledge and skills training towards the construction of a composite competency ecosystem, a transition that relies on in-depth, systematic empirical research as its scientific basis. Peng and Zhu (2021) also emphasized that research on digital intelligence-empowered education needs to move from macro-level descriptions to data-driven precise diagnosis and mechanism elucidation.

In light of this, the primary motivation of this study is to address the identified structural gap by providing a theoretically grounded and empirically validated account of how a professional development support system functions for university music teachers. The core contribution lies in moving beyond descriptive, experience-based recommendations to systematically uncover the multidimensional composition of such a support system and the underlying mechanisms—specifically, the mediating role of digital teaching efficacy—that translate external support into tangible professional development outcomes. By integrating the TPACK framework, self-efficacy theory, and professional learning community theory, this study aims to construct a robust theoretical model and test it through large-scale quantitative data. From the theoretical perspective of digital intelligence technology empowerment, focusing on university music teachers as the research subjects, this study attempts to explore the constituent elements, mechanisms of action, and constructive logic of the professional development support system for university music teachers within the context of digital intelligence empowerment. This will be achieved by constructing a systematic theoretical framework and conducting a large-scale quantitative survey, aiming to provide a reference solution that is both theoretically profound and practically operable for promoting the high-quality development of university music education.

Literature Review

Digital intelligence technology is the product of deep integration between digital technology and artificial intelligence, and its essence in empowering education manifests across three progressive levels: tool substitution, process restructuring, and ecological reshaping.

Zhu and Hu (2022) define educational digital transformation as “a process driven by digital technology that promotes systemic change in educational systems across dimensions such as philosophy, structure, culture, and ecology,” emphasizing that the fundamental purpose of this transformation is to foster holistic human development and the deep occurrence of learning. Peng and Zhu (2021) further proposed a precision teaching framework for smart education, arguing that digital intelligence technology should serve the precise achievement of personalized learning goals, providing every learner with timely, appropriate, and efficient educational support. At the international macro-policy level, the OECD’s (2021) Digital

Education Outlook report points out that emerging technologies such as artificial intelligence and blockchain are fundamentally reshaping teacher roles and educational boundaries, and that teacher professional development support systems must integrate digital technology empowerment elements to establish future-oriented adaptive professional development mechanisms. UNESCO (2021), in its report Reimagining Our Futures Together, emphasizes that education professionals need systematic and sustained professional development support, which should cover multiple dimensions including technical skills, collaborative learning, and institutional safeguards.

The above theoretical review indicates that digital intelligence-empowered education involves the systemic restructuring of educational philosophies, teaching modalities, and teacher roles, a restructuring that carries particular complexity for university music education, which inherently embodies the three attributes of technicality, aesthetics, and creativity.

Domestic research on the professional development of university music teachers has shown an overall trend in recent years of deepening from macro-level description to micro-level mechanism exploration, and progressing from experiential discourse to empirical research. From the perspective of research trajectory, it can be roughly divided into three stages: the 2000s focused primarily on theoretical introduction and experiential summarization, mainly discussing the connotations, pathways, and basic principles of music teacher professional development; the 2010s began to focus on the integration of information technology and music teacher development, yielding a number of empirical studies centered on “information-based teaching competence”; and since the 2020s, with the advancement of educational digital transformation, research focus has gradually shifted to frontier areas such as “digital literacy,” “digital intelligence empowerment,” and “support system construction.”

Zhang’s (2020) study is a representative empirical study of the third stage. Through questionnaire surveys and in-depth interviews, it systematically examined the current status and constraining factors of university music teachers’ information-based teaching competence, finding that their overall competence is at a moderate level, characterized by a structural imbalance of acceptable technical operation skills but significantly insufficient skills in integrating technology into teaching. It identified the lack of systematic training and inadequate incentive mechanisms as key obstacles to competence improvement, and accordingly proposed building support pathways through efforts from both top-level design and grassroots practice.

Wang (2021), from the overall dimension of professional competence development, argued that university music teachers in the digital context should construct a triadic composite competence structure encompassing “subject professional knowledge—digital technology literacy—digital teaching competence,” emphasizing that these three elements are not linearly additive but constitute an interdependent and mutually reinforcing organic whole. Chen (2022), using questionnaire surveys in local normal universities, revealed the practical dilemmas of music teachers’ digital literacy, with her notable contribution being the introduction of a “professional orientation difference” analytical perspective. She found significant differences in digital literacy structures among instrumental music teachers, vocal music teachers, and music theory teachers, and proposed differentiated training strategies based on hierarchical progression.

In international research, the NAfME (2020) report Music Teacher Education: Partnership in a Democracy explicitly emphasizes that technology integration competence should become an indispensable component of music teachers' core competencies, calling for the establishment of systematic support mechanisms to comprehensively enhance music teachers' digital capabilities. UNESCO (2021), in Reimagining Our Futures Together, deeply analyzes the challenges and opportunities for teacher professional development in the digital age, pointing out that education professionals need systematic and sustained professional development support covering multiple dimensions including technical skills, collaborative learning, and institutional safeguards.

At the international academic research level, Bauer (2014) systematically explores the transformative effects of digital technology on music education, proposing that music teachers in the digital age need to achieve organic integration across the three roles of "technology operator," "instructional designer," and "learning facilitator." Mishra and Koehler's (2006) TPACK framework has been widely applied in the field of international music education, while Gaunt and Westerlund (2013) examined the collaborative professional development mechanisms of music teachers from the perspective of professional learning communities.

Synthesizing domestic and international research, the existing literature provides a solid theoretical and empirical foundation for this study, clarifying the core issues in university music teacher professional development, identifying major obstacles such as insufficient systematic training, lack of incentive mechanisms, and neglect of disciplinary specificity, and offering theoretical resources for constructing support systems, including the TPACK framework, professional learning community theory, and self-efficacy theory. However, existing research still presents three significant shortcomings: first, a severe lack of quantitative mechanism research, with empirical studies employing systematic quantitative methods to explore the synergistic effects of various dimensions of the support system being extremely scarce, leaving the relative importance, interaction effects, and pathways of action among dimensions unclear; second, insufficient systematic construction of the support system, as existing research often focuses on isolated examinations of single support elements, lacking systematic construction of the support system as an organic whole; third, weak research on adaptation to the specific context of music education, as how to construct a digital intelligence support system adapted to the music discipline while respecting the essential characteristics of music education—its practicality, aesthetics, and embodiment—remains a theoretical and practical issue urgently needing resolution.

This study integrates self-efficacy theory, the TPACK framework, and professional learning community theory as its theoretical foundation. Bandura's (1997) self-efficacy theory posits that individual behavioral motivation and persistence are driven by efficacy expectations, with digital teaching efficacy serving as a key psychological mediating variable between the professional development support system and actual developmental outcomes. When the support system provides mastery experiences through training, vicarious learning opportunities through communities, and social persuasion through policy recognition, teachers' digital teaching efficacy can be effectively stimulated and strengthened, subsequently transforming into intrinsic motivation for sustained professional development.

Mishra and Koehler's (2006) TPACK framework decomposes teacher knowledge into technological knowledge, pedagogical knowledge, content knowledge, and their intersecting and integrated dimensions, emphasizing that the core competence in technology-integrated teaching lies in the flexible application and organic integration of these three types of knowledge. Huang et al. (2020) further noted that effective technology integration requires a systematic support ecosystem encompassing technology infrastructure, teacher training, instructional support, and evaluation feedback.

In the context of university music education, the application of the TPACK framework has significant disciplinary specificity: the acquisition of music content knowledge heavily relies on embodied practical accumulation, and the introduction of digital intelligence technology not only provides new presentational tools for music teaching but also brings new reflective challenges to the essence and value of music education. Wenger's (1998) community of practice theory reveals the mechanism of collective knowledge construction in the process of social practice, identifying joint enterprise, mutual engagement, and shared repertoire as the three essential elements for effective community functioning. In the context of teacher professional development, professional learning communities provide teachers with a collaborative learning space for peer assistance, collective reflection, and experience sharing, serving as an important mechanism for overcoming the isolation predicament of individual professional development.

OECD (2021) research data also indicates that participation in professional learning communities is one of the most robust external support variables predicting teacher professional development outcomes. These three theoretical frameworks complement each other functionally: self-efficacy theory focuses on "psychological mediation," the TPACK framework focuses on "competence structure," and professional learning community theory focuses on "learning mechanisms." The integrated application of these three enables this study to systematically construct the support system from three dimensions: "competence objectives—psychological mechanisms—learning models."

Through systematic literature review, this study identifies three core research gaps: first, there is a severe shortage of empirical research using systematic quantitative methods to explore the synergistic effects of various dimensions of the professional development support system for university music teachers, leaving the scientific construction of the support system lacking foundational quantitative data; second, existing research often focuses on isolated discussions of single support elements, lacking systematic construction of the support system as an organic whole, and the synergistic mechanisms and structural characteristics among elements have not been fully revealed; third, the deep integration of digital intelligence technology and music education has significant disciplinary specificity, yet existing research has insufficiently focused on how to construct a digital intelligence support system adapted to the music discipline while respecting the essential characteristics of music education—its practicality, aesthetics, and embodiment. Based on these gaps, this study focuses on three core questions: What core dimensions should constitute the professional development support system for university music teachers in the context of digital intelligence empowerment? What are the pathways through which each dimension influences professional development outcomes? What mediating role does digital teaching efficacy play in this process? Based on empirical findings, how can the fundamental principles and core

framework of this support system be systematically constructed? Through systematic answers to these questions, this study aims to provide theoretical foundations and empirical support for the scientific construction of professional development support systems for university music teachers in the context of digital intelligence empowerment.

Research Design

Theoretical Model and Research Hypotheses

This study constructed an integrated theoretical model of digital intelligence empowerment support system—digital teaching efficacy—professional development outcomes.The overall model presents a dual-path structure in which the four dimensions of the support system simultaneously directly predict professional development outcomes while also indirectly predicting professional development outcomes through the partial mediating pathway of digital teaching efficacy. Based on the literature review and theoretical deduction, the following research hypotheses were proposed:

H1–H4: Digital Infrastructure Support (DIS), Professional Learning Community Support (PLCS), Administrative Policy Support (APS), and Technical Skills Training Support (TSTS) each have a significant positive impact on Professional Development Outcomes (PDO).

H5–H8: The four dimensions of support each have a significant positive impact on Digital Teaching Efficacy (DTE).

H9: Digital Teaching Efficacy (DTE) has a significant positive impact on Professional Development Outcomes (PDO).

H10: Digital Teaching Efficacy (DTE) plays a significant mediating role between the four dimensions of support and Professional Development Outcomes.

Variable Measurement

All variables in this study were measured using a 5-point Likert scale (1 = “strongly disagree,” 5 = “strongly agree”). Digital Infrastructure Support (DIS) was developed with reference to the relevant statements regarding the digital teaching environment in the Ministry of Education’s Teacher Digital Literacy (2022), combined with the specific context of university music teaching (professional recording equipment, music software licenses, digital libraries, etc.). Six measurement items were developed, with an example item being: “The university provides sufficient digital hardware equipment for music teaching (e.g., professional recording equipment, electronic keyboard arrays, etc.).” Professional Learning Community Support (PLCS) was developed with reference to the community of practice theoretical framework, encompassing dimensions such as peer assistance, cross-institutional exchange, and online seminars. Five items were developed, with an example item being: “The university actively organizes music teachers to participate in digital teaching case sharing and collective reflection activities.” Administrative Policy Support (APS)encompasses dimensions such as incentive mechanisms, time guarantees, funding support, and performance evaluation. Five items were developed, with an example item being: “The university incorporates teachers’ digital teaching competence into the evaluation system for professional title promotion and performance assessment.” Technical Skills Training Support (TSTS)was developed with reference to the TPACK framework, encompassing dimensions such as training quality, training frequency, and practical application transfer. Six items were developed, with an example item being: The digital music technology training I participate in is closely integrated with the practical context of music teaching. Digital Teaching Efficacy (DTE) was developed with reference to the operational measurement framework of self-efficacy theory, combined with

the digital integration context of music education. Five items were developed, with an example item being: I have full confidence in using digital technology to design and implement high-quality music teaching activities.Professional Development Outcomes (PDO) synthesized the evaluation framework for teacher professional development outcomes, encompassing dimensions such as knowledge renewal, skill improvement, professional identity, and student learning improvement. Seven items were developed, with an example item being: Through participating in digital intelligence-empowered professional development activities, my digital music teaching competence has been significantly enhanced.

Sample and Data Collection

This study employed a stratified cluster sampling method, comprehensively considering factors such as geographical distribution (eastern, central, and western regions), institution type (comprehensive universities, normal universities, and arts institutions), and institution size. From September to November 2023, a questionnaire survey was conducted across 52 universities in 15 provinces (6 eastern provinces, 5 central provinces, and 4 western provinces). The survey targeted in-service teachers responsible for undergraduate music education courses. Electronic questionnaires were distributed with the assistance of the teaching administration departments of the music departments (schools) in each institution. A total of 560 questionnaires were distributed, and 543 were returned (response rate of 96.96%). After data cleaning (excluding questionnaires with excessively short completion times, those failing logical consistency checks, and those with a large number of identical responses), a total of 487 valid questionnaires were obtained (effective rate of 89.69%).

Data Analysis Methods

Descriptive statistics and reliability analysis were conducted using SPSS 26.0. Confirmatory factor analysis (CFA) and structural equation modeling (SEM) were performed using Amos 26.0. The bootstrap method (with 5,000 resamples) was used to test mediating effects, with the confidence interval set at 95%. To control for common method bias (CMB), procedural controls were implemented during the questionnaire design phase, and the Harman single-factor test was conducted post-hoc during the data analysis phase. The results showed that the variance explained by the first common factor was 21.37%, well below the critical threshold of 40%, indicating that common method bias did not pose a substantial threat to the study's conclusions.

Results

Sample Demographics

Table 1

Descriptive Statistics of Sample Demographics (N = 487)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	173	35.5
	Female	314	64.5
Age	Under 30	89	18.3
	30–39 years old	166	34.1

Variable	Category	Frequency (n)	Percentage (%)
	40–49 years old	153	31.4
	50 years old and above	79	16.2
Professional Title	Teaching Assistant / Lecturer	206	42.3
	Associate Professor	186	38.2
	Professor	95	19.5
Teaching Experience	Less than 5 years	93	19.1
	5–10 years	133	27.3
	11–20 years	158	32.4
	More than 20 years	103	21.2
Institution Type	Comprehensive University	187	38.4
	Normal / Teachers' University	158	32.4
	Arts & Music Institution	142	29.2
Highest Educational Degree	Bachelor's Degree or below	40	8.2
	Master's Degree	297	61.0
	Doctoral Degree	150	30.8

From the perspective of the sample structure, the proportion of female teachers (64.5%) is significantly higher than that of male teachers (35.5%), which is in line with the actual situation where the number of female teachers in music departments of universities is relatively large; the proportion of middle-aged and young teachers aged 30-49 is 65.5%, constituting the main force of current university music teachers; teachers with a master's degree or above account for 91.8%, reflecting the high educational level characteristic of the current university music teacher group; the proportion distribution of the three types of institutions is relatively balanced, and the sample represents well.

Descriptive Statistics of Key Variables

Table 2

Descriptive Statistics of Key Variables (N = 487)

Variable	Mean (M)	SD	Skewness	Kurtosis	Theoretical Range
Digital Infrastructure Support (DIS)	3.42	0.71	−0.31	0.18	1–5
Professional Learning Community Support (PLCS)	3.56	0.68	−0.42	0.25	1–5
Administrative Policy Support (APS)	3.38	0.74	−0.28	0.15	1–5
Technology Skills Training Support (TSTS)	3.61	0.69	−0.35	0.22	1–5
Digital Teaching Efficacy (DTE)	3.48	0.72	−0.39	0.19	1–5
Professional Development Outcomes (PDO)	3.53	0.67	−0.44	0.28	1–5

From the mean perspective, the scores of each variable are all concentrated between 3.38 and 3.61, indicating an above-average level. Among them, the perceived scores of technical skills training support (M=3.61) and professional learning community support (M=3.56) are relatively high, while the scores of administrative policy support (M=3.38) and digital infrastructure support (M=3.42) are relatively low. This suggests that there is still significant room for improvement in the support at the administrative policy and infrastructure construction levels, which is consistent with the findings of previous studies revealing a relatively lagging support at the policy level (Zhang Lu, 2020). The absolute values of skewness and kurtosis of each variable are all less than 1, and the data distribution meets the basic requirements of the structural equation model for normality.

Reliability and Validity Analysis

The reliability of the scale was evaluated using Cronbach's α coefficient, and the convergent validity and discriminant validity were assessed through confirmatory factor analysis (CFA). The results are shown in Table 3.

Table 3
Results of Reliability and Validity Analysis

Latent Variable	No. of Items	Cronbach's α	CR	AVE	Factor Loading Range
Digital Infrastructure Support (DIS)	6	0.876	0.891	0.582	0.712–0.821
Professional Learning Community Support (PLCS)	5	0.852	0.869	0.571	0.724–0.812
Administrative Policy Support (APS)	5	0.863	0.878	0.589	0.718–0.825
Technology Skills Training Support (TSTS)	6	0.891	0.903	0.608	0.731–0.843
Digital Teaching Efficacy (DTE)	5	0.869	0.883	0.601	0.742–0.831
Professional Development Outcomes (PDO)	7	0.912	0.923	0.624	

Note: CR represents composite reliability; AVE represents average variance extracted.

The reliability test results show that the Cronbach's α coefficient of all latent variables is above 0.85, and the CR value is above 0.86, indicating that the internal consistency reliability of each scale has reached a relatively high level. In terms of validity, all factor loadings are above 0.70, and the AVE values range from 0.571 to 0.624, all exceeding the 0.50 judgment standard, indicating that each latent variable has good convergent validity. The factor loadings of each item are compactly distributed, indicating that the internal structure consistency of each scale is good.

Further examination of discriminant validity involves calculating the square root of each latent variable's AVE value and comparing it with the correlation coefficient between variables. The results are shown in Table 4.

Table 4
Correlation Matrix of Variables and Test of Discriminant Validity

Variable	M	SD	1	2	3	4	5	6
1. DIS	3.42	0.71	**0.763**					
2. PLCS	3.56	0.68	0.512***	**0.756**				
3. APS	3.38	0.74	0.487***	0.531***	**0.767**			
4. TSTS	3.61	0.69	0.498***	0.564***	0.509***	**0.780**		
5. DTE	3.48	0.72	0.483***	0.527***	0.461***	0.573***	**0.775**	
6. PDO	3.53	0.67	0.501***	0.549***	0.478***	0.598***	0.621***	**0.790**

Note: The bolded diagonal values are the square roots of the corresponding latent variable AVE values; p < 0.001; M is the mean; SD is the standard deviation.

The results in Table 4 show that the square roots of the AVE values of each latent variable are all greater than its correlation coefficient with other latent variables, indicating that the discriminant validity among the six latent variables has reached the Fornell-Larcker judgment

standard. The correlation analysis also reveals that there are significant positive correlations among all the main variables ($p < 0.001$). Among them, the correlation coefficient between digital teaching efficacy and professional development effect is the highest ($r = 0.621$), and the correlation coefficient between technical training support and professional development effect is second ($r = 0.598$). This initially reveals the relative importance of efficacy and training support in predicting professional development effect.

Structural Equation Model Analysis

Before conducting the complete SEM analysis, the overall model's fit was first examined. The initial model was adjusted using the Modification Index (MI) to obtain the final model, and the comparison of the fit indicators is shown in Table 5.

Table 5
Adaptation Indicators of Structural Equation Model

Fit Index	Criterion	Initial Model Value	Final Model Value	Evaluation
χ^2/df	<3.0	3.28	2.47	Acceptable
RMSEA	<0.08	0.071	0.055	Acceptable
CFI	>0.90	0.914	0.951	Acceptable
TLI	>0.90	0.906	0.943	Acceptable
SRMR	<0.08	0.069	0.052	Acceptable

Note: RMSEA represents the Root Mean Square Error of Approximation; CFI is the Comparative Fit Index; TLI is the Tucker-Lewis Index; SRMR is the Standardized Root Mean Square Residual.

All the fit indicators of the final model have reached or exceeded the general judgment standards, indicating that the overall fit of the model to the data is good and the path coefficient analysis can be conducted. The estimated results of the path coefficients are shown in Table 6.

Table 6
Estimation Results of Path Coefficients in Structural Equation Model

Path	Standardized Path Coefficient (β)	S.E.	C.R.	p-value	Hypothesis Testing
DIS → DTE	0.231	0.043	5.371	***	H5Supported
PLCS → DTE	0.287	0.046	6.238	***	H6Supported
APS → DTE	0.198	0.048	4.124	***	H7Supported
TSTS → DTE	0.342	0.044	7.773	***	H8Supported
DIS → PDO	0.148	0.045	3.289	**	H1Supported
PLCS → PDO	0.196	0.048	4.083	***	H2Supported
APS → PDO	0.132	0.049	2.694	**	H3Supported
TSTS → PDO	0.241	0.046	5.239	***	H4Supported
DTE → PDO	0.368	0.052	7.077	***	H9Supported

Note: p < 0.001, p < 0.01; S.E. is the standard error; C.R. is the critical ratio.

The results of the path coefficient analysis indicate that all 9 preset main effect paths reached statistical significance (p < 0.01 or p < 0.001), and H1 to H9 were all supported. Regarding the influence of the four types of support factors on the digital teaching efficacy, the predictive power of technical skills training support was the strongest (β = 0.342), followed by professional learning community support (β = 0.287), digital infrastructure support (β = 0.231), and administrative policy support (β = 0.198). Regarding the direct impact of the four types of support factors on the professional development effect, technical skills training support still ranked first (β = 0.241), followed by professional learning community support (β = 0.196), digital infrastructure support (β = 0.148), and administrative policy support (β = 0.132). The predictive power of digital teaching efficacy on professional development effect was the strongest among all paths (β = 0.368), fully verifying the theoretical prediction that efficacy is a core psychological driving variable.

Mediation Effect Test

The mediating effect of digital teaching efficacy was tested using the Bootstrap method (with 5000 replications and 95% confidence interval). The results are shown in Table 7.

Table 7
Results of Bootstrap Test for Mediating Effect (N = 487, Bootstrap = 5000)

Mediation Path	Direct Effect	Indirect Effect	Boot SE	95%CI Lower	95%CI Upper	Mediating Effect Ratio	Mediation Type
DIS → DTE → PDO	0.148	0.085	0.019	0.051	0.125	36.5%	Some intermediaries
PLCS → DTE → PDO	0.196	0.106	0.021	0.068	0.151	35.1%	Some intermediaries
APS → DTE → PDO	0.132	0.073	0.018	0.041	0.112	35.6%	Some intermediaries
TSTS → DTE → PDO	0.241	0.126	0.023	0.084			Some intermediaries

Note: Bootstrap was repeated 5000 times; Boot SE is the Bootstrap standard error; the proportion of the mediating effect = indirect effect / (direct effect + indirect effect) × 100%; the 95% confidence intervals do not include 0 for all, indicating that the mediating effect is significant.

The results of the Bootstrap test show that the 95% confidence intervals of the four mediating paths do not include 0, indicating that digital teaching efficacy sense has played a significant partial mediating role between the four types of support factors and the professional development effect (H10 is supported). In terms of the mediating effect size, the indirect effect of technical skills training support through digital teaching efficacy sense on the professional development effect is the largest (indirect effect = 0.126), followed by the professional learning community support (indirect effect = 0.106). It is worth noting that the mediating proportions of the four paths are highly similar (34.3% - 36.5%), all around one-third. On the one hand, this proves that digital teaching efficacy sense has a consistent mediating transmission function for all four types of support factors, and on the other hand,

it also indicates that about two-thirds of the influence of each support factor on the professional development effect still belongs to the direct path, and the direct promoting effect of external conditions of the support system cannot be ignored.

Multi-group Analysis: Differences by Institution Type

To test the cross-group robustness of the core path, a multi-group SEM analysis was conducted using institution type (comprehensive universities, teacher training institutions, art colleges) as the grouping variable. The results showed that there were significant differences in the path coefficients on the TSTS → DTE path among the three types of institutions ($\Delta\chi^2 = 8.42$, df = 2, $p = 0.015$): The path coefficient of the art college teachers on this path ($\beta = 0.401$) was significantly higher than that of the comprehensive universities ($\beta = 0.321$) and the teacher training institutions ($\beta = 0.308$), indicating that the activation effect of specialized technical training on the digital teaching efficacy of art college teachers was more prominent. This might be closely related to the professional attributes of art college teachers, which led them to highly identify with the content of music-specific technical training. No significant differences were found in other main paths among the three types of institutions ($p > 0.05$), indicating that the core model of this study has good cross-institution type generalizability.

The Construction Logic of the Professional Development Support System for College Music Teachers

Basic Principles for System Construction

Based on the empirical research conclusions and theoretical analysis, this study holds that the construction of the professional development support system for university music teachers in the context of digital technology empowerment should follow four fundamental principles: systematicness, subjectivity, differentiation, and sustainability. First, the principle of systematicness states that the support system should not be a simple combination of various elements, but rather an organic integration system of technical environment, social culture, institutional system, and individual elements of teachers. The empirical results of this study show that the four dimensions of support, namely digital infrastructure, professional learning community, administrative policies, and technical training, all have significant independent predictive effects on the effectiveness of teachers' professional development. Any single dimension's absence will lead to a reduction in the overall efficacy of the support system. In practice, some institutions have a one-sided support tendency of "emphasizing training, neglecting the community" or "emphasizing facilities, neglecting policies", which precisely requires the correction through the principle of systematicness. Secondly, the principle of subjectivity indicates that digital teaching efficacy perception plays a role of about 35% in mediating between the support system and professional development effectiveness, indicating that the subjectivity of teachers is the core psychological mediator for the effectiveness of the support system. Therefore, the construction of the support system should not only focus on the accumulation and supply of external conditions, but must also fully activate the internal motivation and efficacy beliefs of teachers, and promote teachers to transform from passive acceptance of external support to active planning of self-development and autonomous construction of digital teaching professional identity through the continuous cultivation of efficacy perception. Thirdly, the principle of differentiation reveals that teachers in art colleges have significantly stronger efficacy responses to professional technical training support. This suggests that the design of the support system must fully consider factors such

as institution type, teacher professional direction (singing, instrumental music, music theory, music education), and career development stage (newly hired, growth period, maturity period, leading period), and establish an individualized support mechanism with flexibility and adaptability to avoid the “one-size-fits-all” support supply model that causes resource mismatch and demand dislocation. Finally, the principle of sustainability states that professional development is a dynamic evolutionary process throughout the career of teachers rather than an isolated single training event. The support system should be designed around the entire life cycle of teachers’ professional growth, establish a phased, spiral-upward continuous support mechanism from the digital basic ability construction in the entry adaptation period to the deepening of TPACK integrated application in the growth period, and to the digital innovation leadership in the maturity period, to ensure that the digital technology-enabled professional development support runs through the entire career of teachers and is dynamically updated with the development of digital technology.

The "Three Levels - Four Dimensions - Dual Drive" Framework for the Construction of the Support System for College Music Teachers' Professional Development

Based on the aforementioned principles and empirical data, this study proposes a “Three Levels - Four Dimensions - Dual Drive” framework for the construction of the support system for college music teachers’ professional development, which constitutes the core structure of the system.

The three levels refer to the nested structure of the support system in terms of the structural dimension, which is presented as three levels: macro (policy and institutional level), meso (institutional mechanism level), and micro (individual practice level). The macro policy and institutional level focuses on policy and regulatory guarantees at the national and local government levels, the formulation of national standards for teachers‘ digital literacy (such as the “Teacher Digital Literacy” standard released by the Ministry of Education in 2022), the special funding investment mechanism for music teacher professional development in universities, and the construction of national training platforms; the meso institutional mechanism level focuses on the digital infrastructure configuration at each university, the formulation of professional development plans for the institution, the construction of technical support services, the design of performance incentive policies, and the cultivation of professional learning communities at the institutional level; the micro individual practice level focuses on the planning of digital technology self-learning paths for teachers, peer assistance and cooperation, data-based teaching reflection practices, and the construction of personalized professional development archives at the individual level. The three levels form a vertical connection and mutual promotion mechanism of “macro leadership - meso support - micro activation”, jointly constituting the institutional foundation of the support system.

The four dimensions refer to the functional dimensions of the support system in terms of content, which cover digital infrastructure support, professional learning community support, administrative policy support, and technical training support. The specific connotations of each dimension are as follows. The digital infrastructure support dimension is the material basis of the support system, covering three sub-dimensions: hardware facilities (professional recording studios, digital music classrooms, MIDI keyboard arrays, etc.), software resources (digital audio workstations DAW authorization, music education-specific software, virtual instrument libraries, etc.), and network platforms (music teaching resource libraries, online

collaboration platforms, cloud data services, etc.). Empirical data show that it has a significant positive impact on digital teaching efficacy (β = 0.231) and professional development effects (β = 0.148), and is a material prerequisite for the overall effectiveness of the support system.

The professional learning community support dimension is the social learning mechanism of the support system, covering three sub-dimensions: the construction of digital teaching communities for music teachers within the institution, the construction of cross-institutional professional development networks (such as regional university music teachers' digital teaching alliances), and the operation of online and offline integrated learning communities. Among the four dimensions, its impact on digital teaching efficacy (β = 0.287) and professional development effects (β = 0.196) ranks second, reflecting the indispensable value of social learning and peer assistance in digital ability development. Yu Shengquan (2020) summarized this as the key function of "social network support", pointing out that relying solely on expert training while neglecting peer learning communities in the professional development model has become difficult to adapt to the speed of change in the digital era.

The administrative policy support dimension is the institutional guarantee layer of the support system, which is the key lever for promoting the support system from "spontaneous behavior" to "institutional arrangement". This dimension covers four sub-dimensions: incentive policies (incorporating digital teaching capabilities into the evaluation system for professional promotion), time guarantee (providing flexible class hour arrangements for teachers to participate in professional development activities), funding guarantee (establishing a digital teaching professional development fund), and performance evaluation (establishing a multi-dimensional and dynamic evaluation mechanism for digital teaching quality). Although the direct impact of administrative policy support on efficacy and development effects in the four dimensions is relatively weak (βs are 0.198 and 0.132 respectively), its indispensable role as the fundamental guarantee of the institutional environment is indispensable, and it is the institutional prerequisite for the continuous and effective operation of the other three dimensions. The technical skills training support dimension is the core driving force of the support system and also the dimension with the strongest predictive power in empirical research (β = 0.342 for efficacy, β = 0.241 for development effect). The indirect influence in the mediating effect is also the largest (0.126). This dimension should cover three advanced levels: basic digital music technology skills training (DAW operation, online course production, etc.), training in the integration of technology and music teaching (special enhancement of music education TPACK), and exploration of cutting-edge digital and intelligent technology applications (AI-assisted music creation, intelligent music learning analysis, etc.). It should also be ensured through a complete training loop that the transformation quality is guaranteed.

The dual drive refers to the operating mechanism of the support system relying on the dual-wheel coordinated advancement of "external support drive" and "internal efficacy drive". The external support drive (four dimensions) provides material guarantees, social support, institutional incentives, and knowledge and skill supply for teacher professional development, which are the necessary and sufficient conditions for professional development; the internal efficacy drive (DTE) is a psychological mediating variable that transforms external conditions into actual development effects, activating external conditions into the continuous internal driving force for teachers' autonomous development, and is the decisive factor for

the quality and depth of professional development. The practical significance of the dual drive mechanism lies in that the construction of the support system must simultaneously focus on the coordinated activation of the two driving paths to prevent the two imbalanced states of “adequate external conditions but lack of teacher efficacy” or “high teacher enthusiasm but weak support conditions.”

Theoretical Implications of the System Construction

The proposed framework in this study makes three-fold theoretical contributions at the level of theory.

Firstly, it expands the disciplinary applicability of digital and intelligent empowerment in education research. Existing research on digital and intelligent empowerment in education mostly focuses on K-12 science and technology or general higher education contexts, while paying insufficient attention to the field of university music education, which has unique disciplinary attributes (practicality, physicality, aesthetics, creativity). This study introduces the digital and intelligent empowerment theory into the professional development of university music teachers, revealing the unique laws of digital and intelligent support in art colleges, and providing a typical case for the disciplinary and differentiated development of digital and intelligent empowerment education theory.

Secondly, it verifies and refines the mediating mechanism of efficacy in digital and intelligent teacher professional development. This study precisely estimates the mediating proportion of digital teaching efficacy in four support elements and professional development effects (34.3% - 36.5%) in a quantitative manner, providing specific quantitative evidence for the application of self-efficacy theory in the context of digital and intelligent teacher professional development, and the mediating proportion data can also serve as a reference benchmark for subsequent similar studies.

Thirdly, it provides empirical evidence for the localization application of the TPACK framework in university music education in Chinese universities. This study operationalizes the core concept of TPACK into measurable technical training support dimensions, verifies its significant effect in the context of university music education in China through SEM, and demonstrates the effectiveness and applicability of the TPACK framework in guiding the technical integration professional development of this group.

Practical Approaches of the Support System

Standardization and Specialization of Digital Infrastructure Construction

The construction of digital infrastructure for music education in colleges and universities should follow the dual-track strategy of "standardization as the foundation and specialization for improvement", ensuring both the universal accessibility of basic configurations and the respect for the differentiated needs of different institutions and professional directions. At the standardization level, each university should base its reference on the industry standard for "Teacher Digital Literacy" issued by the Ministry of Education in 2022, and combine the particularity of music subject teaching to establish basic configuration norms for music professional digital teaching environments. This norm should cover three core areas: first, the hardware facilities level, including professional recording equipment, MIDI keyboard arrays, digital audio interfaces, high-fidelity listening systems, digital music classrooms, intelligent musical instrument equipment, etc., to ensure that teachers can complete high-quality digital

music teaching and creative practice; second, the software resources level, including digital audio workstations (DAW) licenses, music notation editing software, virtual instrument libraries, music education-specific software, score scanning recognition tools, etc., to meet the teaching and creative needs of teachers in different professional directions; third, the network environment level, including stable campus network coverage, music teaching cloud storage space, online collaboration platform access, and access rights to digital music resource libraries, to ensure the smooth conduct of teaching activities and the convenient acquisition of resources. Through the establishment and implementation of the above standardized configuration norms, ensure that every music teacher can obtain the necessary software and hardware tools and a stable network environment that meet the basic digital teaching requirements, eliminating the "digital divide" caused by infrastructure differences. At the specialization level, each institution should, based on the specific direction of its music major and the actual situation of its teaching staff, make flexible adjustments and key emphases on the standardized configuration. Specifically, departments specializing in vocal music can prioritize the configuration of high-performance professional recording production systems, acoustic treatment spaces, vocal effectors and audio plugins, supporting recording analysis, sound shaping and work production in vocal music teaching; departments specializing in traditional Chinese instrumental music can prioritize the introduction of traditional instrument digital sampling libraries, virtual simulation performance platforms, and ethnic music analysis software, supporting students' systematic learning of traditional instrument performance techniques and ethnic music styles; departments specializing in piano can prioritize the configuration of digital piano teaching systems, automatic playing pianos, performance analysis software, achieving precise feedback and visual presentation in piano teaching; departments specializing in composition and music theory can focus on the configuration of music notation software licenses, music data analysis tools, composition workstations and sequencers, supporting the digital transformation of composition technique training and music theory teaching; departments specializing in music education can prioritize the configuration of music teaching method digital resource libraries, intelligent teaching evaluation systems, and classroom interaction platforms, promoting the digital innovation of music education courses. At the same time, infrastructure construction should also focus on the establishment of long-term mechanisms, including regular maintenance and update systems for digital equipment, a unified management platform for software licenses, regular iterative assessment mechanisms for new technologies and equipment, and training and technical support services for teachers regarding facility usage, to avoid the "one-time investment, long-term idleness" loose model of infrastructure construction, ensuring that digital infrastructure truly serves the daily teaching and professional development needs of teachers.

Hierarchical Cultivation and Activation of Professional Learning Communities

Professional learning communities are a socialized learning mechanism within the teacher professional development support system. Their implementation requires following a hierarchical construction path of "visible organization - effective operation - deep output", and through a progressive cultivation strategy, fully release the potential of the community. In the "visible organization" stage, the core task is to provide institutional and physical organizational carriers for the professional learning community, transforming the community from an abstract concept into a visible existence. In terms of institutional arrangements, universities should clearly establish organizational forms such as music digital teaching

research workshops, digital teaching practice research groups, and music education technology innovation teams through formal documents, stipulating the activity purposes, member composition, basic responsibilities, and resource support of the community, and granting the community legal status and institutional guarantees; in terms of spatial creation, universities should establish physical places such as music teacher digital teaching exchange rooms, digital music teaching laboratories, and teaching discussion spaces offline, and set up digital fields such as collaboration platform sections, virtual teaching rooms, and resource co-construction and sharing spaces online, providing teachers with a combination of physical and virtual activity spaces. In the "effective operation" stage, the core task is to ensure that the continuous activities of the community do not become a formality, forming a regular and dynamic operation mechanism. Establish regular communication mechanisms, such as a monthly digital teaching case sharing meeting, a semester-long cross-university digital teaching observation and discussion, and an annual music teacher digital teaching achievement exhibition, making the community activities a predictable fixed arrangement in teachers' professional lives; design cross-university visitation systems, establishing cooperation mechanisms with other regional music departments of universities, organizing teacher visits and observations, joint teaching research and teaching exchanges, to expand the community's vision and resource boundaries; plan joint digital teaching research projects, forming cross-university project teams around common issues in digital music teaching (such as the application of AI-assisted music creation teaching, the integration strategy of virtual instruments in instrumental teaching, etc.), conducting collaborative research and teaching experiments, to drive the deep participation of community members through project-driven methods. In the "deep output" stage, the core task is to guide community members to convert the learning outcomes of the common learning into valuable public outputs, through the recognition and incentives of the output results to strengthen the community members' sense of belonging and the intrinsic motivation for continuous participation. Specifically, the community should systematically sort out and consolidate collective wisdom, forming various forms of output results such as teaching improvement records (such as digital teaching practice reflection logs, classroom observation records, teaching improvement plans, etc.), research results of topics (such as digital music teaching research papers, teaching reform projects, school-based textbook development, etc.), digital teaching resources (such as high-quality digital teaching case libraries, music teaching micro-lesson resource packages, course teaching design templates, etc.). The university should formally recognize these output results and incorporate them into the teacher professional development archives, teaching achievement evaluation systems, and professional title promotion evaluation frameworks, ensuring that the intellectual contributions of community members receive the appropriate institutional rewards. Additionally, fully leverage digital technology to break through geographical boundaries, actively build a digital community for university music teachers in cross-regional and cross-university settings, through diversified forms such as online live streaming sharing, cloud workshops, asynchronous discussion forums, to expand the scale benefits and coverage of the professional learning community, especially providing equal participation opportunities for music teachers in remote areas or institutions with weak teaching resources, enabling them to cross geographical barriers and integrate into the national or even international music teacher professional development network, truly achieving extensive connection and coordinated development of the professional learning community.

Systematic Collaborative Design of Administrative Policy Support

The effectiveness of administrative policy support depends on the coordinated efforts of three policy tools: incentives, guarantees, and evaluations. Any single tool operating in isolation is unlikely to generate sustained institutional efficacy. It is necessary to achieve the organic integration and mutual reinforcement of these three tools within a systematic design framework. In terms of the incentive mechanism, it is suggested that universities incorporate the development effectiveness of teachers' digital teaching capabilities into the comprehensive evaluation framework of professional title assessment, job performance evaluation, and performance rewards. Through institutional recognition, it guides teachers to internalize the improvement of digital capabilities as an important dimension of their career development. Specifically, in the professional title assessment, the development achievements of digital music teaching resources, digital teaching reform projects, digital teaching competitions, and digital teaching research papers should be clearly recognized as representative achievements; in job performance evaluation, process indicators and outcome indicators for the development of digital teaching capabilities should be set, avoiding using only class hour quantity or student evaluations as the sole assessment basis; in performance rewards, a special digital teaching award should be established to provide substantive incentives to teachers who have made outstanding contributions in digital music teaching innovation, high-quality digital resource construction, and digital teaching research. Through the above institutional arrangements, teachers can clearly perceive the positive correlation between digital teaching capability development and their career development prospects, thereby transforming professional development activities from an "extra burden" to an "organic component of career growth". In terms of the guarantee mechanism, universities should provide necessary time, funds, and organizational support for teachers to participate in digital professional development activities, reducing the participation cost to an acceptable level and eliminating teachers' concerns. In terms of time guarantee, the institution should appropriately reduce class hours during the teachers' participation in systematic training or incorporate professional development activities into the teaching workload accounting system, enabling teachers to obtain time resources for professional growth without sacrificing normal teaching work. In terms of financial support, the institution should establish a special fund for digital teaching development of music teachers, supporting teachers to participate in relevant conferences and training abroad and at home, purchasing digital teaching tools and resources, and conducting digital teaching research projects, providing an economic foundation for teachers' active exploration. In terms of organizational support, the institution should establish a digital teaching support service center or technical consultation team to provide daily technical consultation, teaching design, and resource construction services for teachers, reducing the technical threshold for teachers' independent exploration. In terms of the evaluation mechanism, a dynamic assessment system for teachers' digital teaching capabilities based on process data should be established to accurately identify the focus of support resources through diagnostic assessment, replacing simple result-based assessment with developmental assessment, and truly fulfilling the essence of assessment as "driving growth rather than proving results". The assessment content should cover multiple dimensions such as the update level of teachers' digital teaching concepts, the practical level of integrating technology into teaching, the contribution of digital resources development and sharing, and the depth of participation in professional learning communities; the assessment methods should introduce diverse methods such as teaching portfolios, classroom video analysis, student work analysis, and peer review to avoid the one-sidedness

of single quantitative scoring; assessment feedback should be provided promptly, specifically, and constructively to teachers, helping them identify their strengths and improvement directions, and based on the assessment results, matching them with personalized professional development support resources. Through the coordinated design and systematic promotion of the three policy tools of incentives, guarantees, and evaluations, administrative policy support can be transformed from fragmented and temporary measures to systematic and continuous institutional arrangements, providing solid external institutional guarantees for the professional development of music teachers in universities.

Full-chain Closed-loop Optimization of Technical Skills Training

Given that technical skills training support holds the strongest predictive power in empirical research, its optimization design is particularly crucial. This study suggests constructing a "layered progressive - professional embedding - practice-oriented - continuous follow-up" full-chain training model, transforming the training from an isolated single activity into a systematic support mechanism throughout the entire process of teachers' professional growth. Layered progressive aims to design differentiated progressive content systems based on teachers' starting levels of digital literacy, achieving precise allocation of training resources and personalized supply. Specifically, a three-level progressive content system should be constructed: the basic layer for teachers at the beginning of digital literacy, focusing on the standardized operation of digital tools and basic function mastery, including basic operations of digital audio workstations, basic use of music notation software, application of online teaching platforms, and retrieval and acquisition of digital teaching resources, helping teachers establish the basic technical foundation for digital teaching; the intermediate layer for teachers with certain digital literacy foundation, focusing on the integration application design of technology and music teaching activities, including embedding strategies of digital tools in classroom teaching, design and implementation of mixed music teaching models, personalized learning guidance supported by digital technology, and collection and analysis application of teaching data, promoting teachers to move from "being able to use technology" to "improving teaching with technology"; the innovative layer for teachers with higher digital literacy and the willingness to explore innovation, focusing on the teaching exploration and creative application of cutting-edge digital technologies, including teaching practice with AI-assisted music creation, music learning big data analysis and personalized feedback, application of virtual reality and augmented reality in music teaching, and innovation of human-computer collaborative music teaching models, leading teachers to stand at the forefront of the integration of digital technologies and music education. Through pre-assessment of digital literacy, each teacher can be accurately positioned at the appropriate starting level and advancement path, avoiding the resource mismatch caused by "one-size-fits-all" training where "those with good foundation do not have enough to eat and those with poor foundation cannot keep up". Professional embedding emphasizes that the training content must be deeply integrated with the characteristics of the music discipline, rather than simply transplanting general information technology training content to the music teaching scenario. The training content should cover the teaching application of music education-specific digital tools, such as classroom application strategies of Sibelius, Finale, Dorico music notation software, music creation teaching design of Logic Pro, Ableton Live, Cubase digital audio workstations, classroom practice of online music notation collaboration platforms, and educational application of specialized software such as MuseScore, Noteflight, intelligent instrument teaching systems, sight-reading and ear training training software, and music

appreciation analysis tools. At the same time, the training content should actively introduce cutting-edge integration technologies, including exploration of teaching application of AI-assisted music creation tools, application of music learning big data analysis in student performance assessment, design and implementation of virtual reality and augmented reality music hall experiences, and integration of intelligent accompaniment systems, to keep the training content in line with technological development and maintain forward-looking and leading characteristics. Practice-oriented means using real teaching problems as the driving force of training, deeply binding technical skills training with specific teaching scenarios, significantly reducing the proportion of pure technical lectures disconnected from teaching practice. The training format should adopt practical models such as workshops, classroom observation and evaluation, micro-teaching and video reflection, teaching design workshops, lesson study and collective lesson planning, allowing teachers to learn technical application in real or simulated teaching scenarios and master methods of integrating technology in the process of solving real teaching problems. For instance, during the training, teachers can be required to design a technology integration plan based on the music lesson they are about to teach, and conduct a trial lecture and peer evaluation during the training; or they can be organized into groups to create digital teaching resources specifically for certain music knowledge points, and test the teaching effectiveness of these resources in practice. Through the "learning by doing and using" approach, it is ensured that after the training, teachers can immediately convert what they have learned into classroom practice, achieving seamless connection between training and teaching. Continuous follow-up is the core feature that distinguishes the full-chain training from traditional single-training sessions. Its purpose is to break the short-term model of "training ends, learning ends", and ensure that the training effect is maintained and continuously deepened in the practical context. Specific measures include: establishing a technical application support mechanism after the training, such as setting up an online technical support service desk, opening a technical consultation hotline, and establishing a knowledge base of common problems, to provide immediate support for teachers' technical problems when they return to the teaching position after the training; opening the digital teaching resource library, integrating the teaching cases, course resources, and tool software used in the training into a sustainable-accessible resource platform, allowing teachers to consult and use it at any time; establishing a training effect tracking mechanism, conducting regular training effect surveys and teaching practice application evaluations to understand the teachers' technical application situation, difficulties encountered, and continuous support needs after the training, and accordingly adjusting the subsequent training content and support strategies; establishing a training follow-up activity mechanism, such as organizing post-training teaching practice sharing sessions, cross-university tracking observations, and advanced training courses, providing continuous communication and learning platforms for teachers. Through the coordinated implementation of the above measures, a complete professional growth loop from training to practice and then to reflection and improvement is formed, making the technology training truly become an engine for promoting the continuous improvement of teachers' digital teaching capabilities, rather than an isolated, one-time knowledge dissemination activity.

Conclusion

This study takes the perspective of digital technology empowerment as the entry point. Through a large-scale questionnaire survey of 487 university music teachers from 15 provinces across the country and a structural equation model analysis, it systematically

examined the constituent dimensions and mechanism of the professional development support system for university music teachers, and reached the following main conclusions. First, in the context of digital technology empowerment, the professional development support system for university music teachers consists of four core dimensions: digital infrastructure support, professional learning community support, administrative policy support, and technical skills training support. All four dimensions have a significant positive impact on the professional development effect, verifying the overall construction logic of the "multi-dimensional synergy" of the support system. The absence of any single dimension will restrict the overall efficacy. Second, technical skills training support is the strongest support factor for predicting digital teaching efficacy and professional development effect, followed by professional learning community support. This finding has direct practical guiding significance for the resource allocation focus of the support system construction, suggesting that specialized and practical technical training and community building should be prioritized as areas of resource investment. Third, digital teaching efficacy has a significant partial mediating effect between the support system and professional development effect. The mediating ratio is approximately 35%, confirming the key role of efficacy as a psychological mediating mechanism, indicating that the construction of the support system must provide external conditions while also highly emphasizing the activation and strengthening of teachers' internal digital teaching efficacy beliefs. Fourth, the type of institution has a significant moderating effect on the path from technical skills training support to digital teaching efficacy. Teachers from art colleges have a more prominent response to the efficacy of specialized technical training, suggesting that the design of the support system should fully consider the differences in institutional contexts and establish an elastic support mechanism that combines differentiation and adaptability. It should be noted that this study has the following limitations: The cross-sectional survey design makes it difficult to track the long-term dynamic changes of the effects of each element of the support system; although the sample covers 15 provinces across the country, the development levels of university music education in each province are significantly unbalanced, and there is still room for further optimization of the regional representativeness of the sample; The self-reporting scale used for measurement may have a certain degree of social expectation bias; With the rapid popularization of generative artificial intelligence (such as AI music generation tools), its new impact on the professional development support needs of university music teachers has not been fully reflected in the framework of this study. Looking to the future, the integration of digital technology and university music education will continue to deepen, and the research on the professional development support system for university music teachers needs to be further advanced in the following directions: Deepen the application research of artificial intelligence in the personalized professional development path design for music teachers, explore precise support models based on learning analysis technology; Strengthen the long-term tracking research on the implementation effect of the support system and rich qualitative field research, supplementing the depth of the micro-narrative dimension beyond the macro-quantitative picture; Promote cross-national comparative research to systematically draw on international advanced experience to improve the construction of the support system for university music teachers in China; Focus on the support needs for emerging professional abilities such as digital creativity and human-computer collaborative teaching ability, providing forward-looking theoretical support and practical references for the continuous iteration of the professional development support system for university music teachers in the digital age.

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