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RESEARCH ARTICLE

Interdisciplinary study on environmental support and cognitive regulation enhancing music creativity in Orff Schulwerk for non-music major college students

Jinyi Yu[1,2,*], Marissa Ejercito - Borines[3]

[1] *Doctoral student, College of Arts, Sciences, and Education. Trinity University of Asia, Quezon City, 1102, Philippines*

[2] *Professor, School of Arts, Qingdao university, Qingdao, China, 266071*

[3] *Doctor, Faculty & Program Chair, College of Arts, Sciences, and Education. Trinity University of Asia, Quezon City, 1102, Philippines*

*** Corresponding author:** Jinyi Yu, jinyinyu@tua.edu.ph

ABSTRACT

Based on an interdisciplinary perspective, this study explores the mechanisms by which environmental support and cognitive regulation enhance musical creativity among non-major university students in Orff improvisation. A quasi-experimental design was employed, selecting 400 non-major university students as research participants. The experimental group received Orff improvisation instruction integrated with environmental support and cognitive regulation strategies, while the control group received traditional music instruction, with an intervention period of 16 weeks. The study utilized mixed methods, collecting data through questionnaire surveys, behavioral observations, work analysis, and in-depth interviews, and analyzing the data using descriptive statistics, analysis of variance, regression analysis, and structural equation modeling. The results indicate: (1) Environmental support and cognitive regulation demonstrate significant synergistic effects; when environmental support reaches optimal configuration, students' cognitive regulation efficacy improves by 67.3%, and overall musical creativity enhances by 78.2%; (2) The three stages of Orff improvisation present differentiated environment-cognition interaction patterns: the imitation stage primarily optimizes cognitive load, the exploration stage promotes metacognitive development, and the improvisation stage releases cognitive freedom; (3) Demographic characteristics play important moderating roles in environment-cognition interactions, with gender differences mainly manifested in environmental support preferences and age differences reflected in the maturity of cognitive regulation strategies; (4) Musical creativity enhancement is achieved through four pathways: cognitive load optimization, emotional arousal regulation, social belonging construction, and self-efficacy enhancement, demonstrating significant psychological and social effects; (5) The constructed interdisciplinary theoretical framework successfully explains the complex mechanisms of musical creativity development, with the overall model explanatory power reaching 73.4%. The proposed "ecological-cognitive" teaching model provides scientific guidance for music education practice, and the developed assessment tools for environmental support and cognitive regulation establish a foundation for subsequent research. This study enriches the theoretical system of music education, expands the application domains of environmental psychology and cognitive psychology, and provides important theoretical foundations and practical pathways for cultivating innovative talents and promoting

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students' comprehensive development.

Keywords: environmental support; cognitive regulation; Orff improvisation; musical creativity; non-major university students; interdisciplinary research

1. Introduction

In today's globalized educational context, how to effectively enhance the musical creativity of non-major university students has become an important issue in the field of music education. Musical creativity is not only a significant manifestation of individual artistic literacy, but also a key pathway for cultivating innovative thinking and comprehensive qualities. However, traditional music education models often focus on skill training and knowledge transmission, lacking systematic cultivation of learners' creative thinking. The Orff teaching method, with its unique improvisation concepts and experiential learning approaches, provides new possibilities for cultivating musical creativity. Meanwhile, with the in-depth development of educational psychology and environmental psychology research, scholars have gradually recognized the important roles of environmental support and cognitive regulation in the learning process. Wang E (2015) pointed out in research on experiential teaching of music subjects in information environments that good instructional environment design can significantly enhance students' music learning experience and learning outcomes [1]. This provides important theoretical support for exploring musical creativity cultivation from an interdisciplinary perspective, and also highlights the necessity and urgency of introducing environmental support and cognitive regulation theories into Orff improvisation teaching research.

From a theoretical perspective, Specifically, this study employs Gibson's Affordance Theory to explain how musical learning environments provide students with specific behavioral possibilities, namely how physical and social elements in the environment offer supportive cues for musical creative activities; applies Kaplan and Kaplan's Attention Restoration Theory to elucidate how appropriate musical learning environments restore students' cognitive resources through four dimensions—fascination, being away, compatibility, and extent—thereby creating optimal psychological states for the expression of creativity. Meanwhile, this study draws upon Tajfel's Social Identity Theory to understand how group belonging in musical group activities influences students' participation motivation and performance levels, and utilizes the three basic psychological needs of autonomy, competence, and relatedness from Deci and Ryan's Self-Determination Theory to explain the intrinsic driving mechanisms of environmental support and cognitive regulation. Environmental support theory emphasizes the promoting effect of external environments on individual learning and development, while cognitive regulation theory focuses on the management and optimization of individual internal cognitive processes. The organic combination of these two theoretical dimensions provides a new analytical framework for understanding the internal mechanisms of Orff improvisation teaching. Andrea et al. (2023) found in peer tutoring research that supportive learning environments can effectively improve students' musical performance, particularly in intonation training for violin and viola[2]. This finding indicates that environmental factors play a non-negligible role in music learning. Meanwhile, Lijuan's (2023) research on memory mechanisms in sight-singing and ear training teaching revealed the important value of cognitive regulation in music learning, confirming that reasonable cognitive regulation strategies can significantly enhance music school students' musical memory and auditory abilities[3]. These research findings lay a solid foundation for the theoretical construction of this study and demonstrate the scientific value of exploring musical creativity cultivation from the dual dimensions of environmental support and cognitive regulation.

At the practical application level, current music education faces numerous challenges and opportunities. On one hand, the rapid development of information technology has created richer environmental support conditions for music education. As Sun Jian (2025) pointed out, the integrated media environment provides new breakthrough pathways for music dissemination[4], and Guan Jiajia (2025) also emphasized the important impact of new media environments on music art dissemination and promotion[5]. On the other hand, the anxiety and stress problems commonly existing among students in the music learning process also need to be addressed through effective cognitive regulation strategies. Research by N.E.N et al. (2022) found that appropriate music education training can effectively alleviate performance anxiety and stress responses among music major students, providing important evidence for understanding the practical utility of cognitive regulation in music learning[6]. However, existing research mostly focuses on single-dimensional exploration, lacking in-depth analysis of the synergistic mechanisms between environmental support and cognitive regulation, particularly systematic research in the specific teaching context of Orff improvisation remains insufficient.

Based on the above analysis, this study aims to construct an interdisciplinary research framework integrating environmental psychology, social psychology, and music education, deeply exploring the synergistic mechanisms of environmental support and cognitive regulation in Orff improvisation and their effects on enhancing musical creativity among non-major university students. The systematic analysis method proposed by Xu Penghao et al. (2025) in spatial intuitive planning environmental impact assessment research provides important methodological insights for this study[7]. Through the adoption of mixed research methods, this study will conduct comprehensive analysis from multiple dimensions including individual cognitive characteristics, environmental support elements, and teaching process mechanisms, striving to reveal the deep interactive patterns between environment and cognition in Orff improvisation teaching. The research results will not only help enrich the theoretical system of music education, but also provide scientific evidence and practical guidance for enhancing non-major university students' musical literacy and cultivating innovative abilities, holding important theoretical value and practical significance. The interdisciplinary theoretical framework constructed in this study is based on the theoretical integration of three core disciplinary domains: environmental psychology provides the theoretical foundation for external support systems, cognitive psychology reveals the operational patterns of internal regulation mechanisms, and music education defines the professional connotations of creativity development. These three domains achieve organic integration through the dynamic interactive chain of "environment-cognition-behavior." Specifically, environmental psychology's ecological systems theory (Bronfenbrenner) and environmental stress theory (Mehta) provide frameworks for understanding the hierarchical structure and operational mechanisms of physical, social, and technological environmental support; cognitive psychology's cognitive load theory (Sweller), metacognitive theory (Flavell), and self-regulated learning theory (Zimmerman) explain how individuals manage and optimize cognitive resources; music education's creativity development theory (Webster) and experiential learning theory (Kolb) elucidate the specificity and regularity of musical creative processes. The core logic of integration is that environmental support influences cognitive regulation processes through pathways such as reducing cognitive load, providing cognitive scaffolding, and stimulating intrinsic motivation; cognitive regulation promotes musical creativity performance through mechanisms such as metacognitive monitoring, strategy selection, and self-assessment; while the development of musical creativity, in turn, enhances individuals' ability to utilize environmental resources and the autonomy of cognitive regulation, forming a spiraling upward developmental pattern. This interdisciplinary framework transcends the limitations of single-disciplinary perspectives and provides a more comprehensive and profound theoretical explanation for the complex phenomenon of musical creativity.

2. Literature review

Musical creativity, as an important component of human cognitive ability, has always been a core issue in music education research. From the perspective of environmental support, the construction of music learning environments has profound impacts on learners' creativity development. Yu Jinghan and Jiang Cong (2025) developed a family music environment scale for preschool children, providing scientific measurement tools for understanding the importance of early music environments on individual development. This study emphasized the fundamental role of environmental factors in musical ability cultivation [8]. In the physical space dimension, Chung et al. (2024) conducted an in-depth investigation of the acoustic environment for student music practice, finding that appropriate acoustic environments can significantly affect students' practice effectiveness and musical performance[9]. This finding echoes the research by Wang Huiyi and Cheng Xiao (2024) on the operation of environmental chamber musical theater from a third space perspective, which revealed the crucial role of environmental design in musical artistic performance [10]. Regarding technology-supported learning environments, Li Shuo and Lu Jing (2024) explored the construction of smart teaching classroom environments for music majors in art colleges, pointing out that modern information technology provides new possibilities for optimizing music education environments [11]. These studies collectively demonstrate that whether physical, social, or technological environments all have important impacts on music learners' cognitive development and creativity performance, laying a solid empirical foundation for the application of environmental support theory in this study.

From the theoretical perspective of cognitive regulation, individuals' cognitive management and self-regulation abilities during music learning have decisive impacts on learning outcomes. Hui et al. (2023) used hierarchical linear modeling to study the effects of elementary principal support and teaching characteristics on students' music academic achievement, finding that effective support systems can enhance learning outcomes by strengthening students' cognitive regulation abilities [12]. This finding complements the research by Huawei and Jenatabadi (2024) on the impact of social support on music performance anxiety among university music students, which revealed through chain mediation analysis that social support alleviates music performance anxiety through the mediating effects of emotional intelligence and self-efficacy [13]. At the individual difference level, Ruiz et al. (2025) explored the relationships among university students' music preferences, personality traits, stress, and music consumption, providing important insights for understanding how individual cognitive characteristics influence music learning and creation[14]. These studies indicate that cognitive regulation involves not only individual metacognitive strategies but also multiple dimensions including emotional regulation, stress management, and self-efficacy. Particularly in high cognitive load tasks such as musical improvisation, effective cognitive regulation strategies play a crucial role in creativity performance.

In the research field of technology environment and music education integration, scholars have explored various innovative teaching models and environmental designs. Wang Wenqian (2024) studied innovation and practical strategies for ethnic music teaching in colleges under the all-media environment, emphasizing the important role of multimedia technology in enriching music teaching environments[15]. Chen Yongyan (2024) focused on the integration and innovation of micro-lesson teaching resources for junior high school music in new media environments, providing practical cases for understanding technology-supported personalized learning environments[16]. Hu Xueting and Li Dianyang (2024) further explored the construction of deep teaching models for college music in virtual reality environments, demonstrating the application potential of immersive technology in music education [17]. Yan (2024) analyzed from a macro perspective the impact of internet big data development on university music education, pointing out that data-driven personalized learning environments can better adapt to learners' individual needs [18]. Wen Jing (2024) [19] and Liu Lina (2024)[20] respectively explored music teaching model innovation based on information environments from college and elementary school perspectives, providing references for environmental support strategies at different educational stages. These studies collectively reveal that technology environments not only provide rich resources and tools for music learning but more importantly create new learning spaces that support cognitive regulation and creative thinking development.

Synthesizing the above research, the synergistic mechanisms between environmental support and cognitive regulation in music education are gradually becoming clear. Chen Xiang (2024) proposed in research on high school music characteristic development under new media environments that the combination of environmental innovation and teaching method reform is key to improving music education quality [21]. Guo Dongliang (2024)[22] and Ye Yao (2024)[23] respectively explored from the perspectives of piano teaching innovation and traditional music culture inheritance how new media environments promote deep development in music learning. These studies indicate that effective environmental support can stimulate learners' intrinsic motivation, while good cognitive regulation abilities can help learners better utilize environmental resources. Under an interdisciplinary theoretical framework, research by Biswas et al. (2019) on the impact of environmental music on consumer behavior[24], and Lasen's (2018) research on mobile music listening as portable urbanism, provide new perspectives for understanding the complex relationship between environment and music cognition[25]. Fu Linqing (2024)[26] and Shang Shuai (2024)[27] respectively explored the impact of environmental factors on music perception and creation from the perspectives of urban sound environments and natural geographical environments, further enriching the theoretical connotations of environment-cognition interactions.

However, existing research still has shortcomings in several aspects: First, there is a lack of in-depth research specifically targeting the Orff improvisation teaching method; Second, the synergistic mechanisms between environmental support and cognitive regulation have not been sufficiently elucidated; Third, the musical creativity development patterns of non-major university students need more empirical support. Therefore, this study will construct an integrative framework of environmental support and cognitive regulation based on existing theoretical foundations, providing scientific evidence for theoretical construction and practical improvement of Orff improvisation teaching.

3. Research methods

3.1. Research design

This study employs a mixed methods research design, combining the advantages of quantitative and qualitative research to construct an interdisciplinary analytical framework for environmental support and cognitive regulation in Orff improvisation. The research design is based on social ecological systems theory and cognitive load theory, dividing environmental support into three dimensions: physical environmental support, social environmental support, and technological environmental support, and cognitive regulation into three levels: metacognitive regulation, emotional regulation, and behavioral regulation, forming a 3×3 theoretical matrix model. In terms of experimental design, a quasi-experimental research design is adopted, selecting two groups of non-major university students as experimental and control groups. The experimental group receives Orff improvisation instruction integrated with environmental support and cognitive regulation strategies, while the control group receives traditional music instruction [28]. The experimental period spans 16 weeks, with 2 class hours per week, totaling 32 hours of instructional intervention. To ensure the ecological validity of the research, the experiment is conducted in authentic music classroom environments, with teaching content strictly following the three progressive stages of Orff pedagogy: imitation-exploration-improvisation. Additionally, a longitudinal research design is employed, collecting data at three time points:

before, during, and after the instructional intervention, to track the dynamic changes in students' musical creativity development. Physical environment support includes acoustic environment optimization (reverberation time controlled at 0.8-1.2 seconds, background noise ≤35dB, audio equipment frequency response range 20Hz-20kHz), spatial layout design (movable seating configuration, circular or U-shaped arrangement, activity space ≥2.5 square meters per person), lighting condition adjustment (combination of natural and artificial light, illuminance maintained at 500-800 lux), and instrument resource allocation (Orff instrument sets including xylophones, metallophones, percussion instruments, etc., with no fewer than 15 types); social environment support is operationalized as teacher support systems (teacher-student ratio controlled within 1:8, providing timely feedback frequency ≥6 times/class period, encouraging language usage ratio ≥80%), peer interaction networks (group size of 3-4 people, structured interactive activities ≥4 per class period, combination of peer evaluation and self-assessment), and group atmosphere creation (non-judgmental creative environment, error tolerance indicators, positive emotional expression encouragement mechanisms); technical environment support specifically includes multimedia equipment configuration (high-fidelity audio systems, real-time recording equipment, tablet computers or smartphone applications), digitized teaching resources (music composition software, metronome applications, audio material libraries), and interactive platform construction (online collaboration tools, work-sharing platforms, instant feedback systems). All environmental elements establish quantitative assessment standards, using 5-point Likert scales for regular monitoring and dynamic adjustment. The experimental group intervention design specifically includes: Weeks 1-4 imitation phase (environmental support strategies: circular seating arrangement to promote audiovisual communication, using xylophones and metallophones for echo games and rhythm imitation exercises; cognitive regulation strategies: teacher demonstration of "listen-think-do" three-step strategy, students maintain metacognitive journals), Weeks 5-8 exploration phase (environmental support strategies: small group collaboration area setup, providing shakers, triangles and other percussion instruments for timbre exploration; cognitive regulation strategies: introduction of "plan-execute-reflect" cycle, combination of peer evaluation and self-monitoring), Weeks 9-12 improvisation phase (environmental support strategies: open space layout, free choice of diverse instrument combinations; cognitive regulation strategies: pre-creation goal-setting cards, emotion regulation techniques during creation, post-creation recorded work playback analysis), Weeks 13-16 integration and enhancement phase (comprehensive application of previous strategies, addition of cross-group presentations and collective creation projects). The control group employed traditional music teaching methods: fixed seating arrangement, teacher-dominated theoretical instruction, standardized music theory exercises, individual independent completion of assigned repertoire practice, lack of systematic environmental optimization and cognitive strategy guidance, with evaluation methods primarily focused on skill testing. Specific teaching tools include: experimental group used cognitive strategy prompt cards, self-assessment scales, group collaboration record sheets, multimedia feedback systems; control group used only traditional textbooks, staff notation exercise books, and basic instruments.

In terms of theoretical framework construction, this study integrates supportive environment theory from environmental psychology, social cognitive theory from social psychology, and dual coding theory from cognitive psychology, establishing a causal chain model of "environmental support-cognitive regulation-creativity performance." The research adopts multiple validation strategies, employing various data collection methods including questionnaire surveys, behavioral observations, work analysis, and in-depth interviews to ensure the reliability and validity of research results. At the data analysis level, quantitative data employs descriptive statistics, analysis of variance, regression analysis, and structural equation modeling, while qualitative data uses thematic analysis and grounded theory analysis methods [29].

To control potential confounding variables, the research design incorporates covariates such as students' musical foundation, learning motivation, and personality characteristics, and combines random grouping with matched design to maximize internal validity. Furthermore, the research designs a formative assessment mechanism that monitors the implementation quality of instructional intervention and changes in students' learning states in real-time through weekly teaching reflection logs, student self-assessment forms, and peer evaluation forms, providing rich contextual information for subsequent data interpretation and theoretical construction.

3.2. Research subjects and sampling methods

The target population for this study consists of non-music major university students aged 18-23, aligning with the cognitive developmental characteristics and music learning needs of higher education learners. Based on research design requirements and statistical power analysis, a mixed sampling method combining stratified random sampling and convenience sampling is employed to select research subjects from different colleges within Qingdao University, Shandong Province, China. All participants in both the experimental and control groups are students from Qingdao University, Shandong Province, China, ensuring consistency in educational background and cultural context. First, stratification is conducted within each university according to college types (science and engineering, humanities and social sciences, economics and management) to ensure diversity in disciplinary backgrounds of the sample. Second, classes are randomly selected as sampling units within each stratum to avoid individual selection bias. The total sample size is determined to be 400 students, with 200 in the experimental group and 200 in the control group. Based on effect size estimates from previous related studies and requirements for a significance level of 0.05 and statistical power of 0.80, this sample size can meet the needs of statistical analysis. Regarding sample characteristic control, research subjects must meet the following inclusion criteria: no music major learning background, no severe hearing impairment, voluntary participation in the study with signed informed consent. Exclusion criteria include: those who have received systematic music training for more than two years, those with severe mental illness history, and those participating in other music teaching experiments during the study period[30]. The demographic composition of the sample is as follows: gender distribution comprised 300 females (75%) and 100 males (25%); age distribution included 286 participants aged 18-19 (71.5%), 84 aged 20-21 (21%), and 30 aged 22-23 (7.5%), with a mean age of 19.2 years (SD=1.1); regarding cultural background, there were 356 Han Chinese students (89%) and 44 ethnic minority students (11%), including 18 Manchu, 12 Hui, 8 Mongolian, and 6 Uyghur participants; geographic origins encompassed 156 from North China (39%), 98 from East China (24.5%), 76 from South China (19%), 42 from Southwest China (10.5%), and 28 from Northwest China (7%); academic field distribution included 145 in science and engineering (36.25%), 138 in humanities and social sciences (34.5%), and 117 in economics and management (29.25%); regarding previous musical experience, 218 participants had no musical learning experience whatsoever (54.5%), 126 had simple musical exposure during kindergarten to elementary school (31.5%), 56 had participated in musical clubs or elective courses during middle and high school (14%), and 0 participants had received 1-2 years of instrumental training without reaching professional level (strict adherence to exclusion criteria); family socioeconomic status was comprehensively assessed using parental educational attainment and occupational categories, resulting in 132 high-SES families (33%), 201 middle-SES families (50.25%), and 67 low-SES families (16.75%); urban-rural background distribution included 258 from cities (64.5%), 94 from county towns (23.5%), and 48 from rural areas (12%). This detailed demographic composition provides important reference for evaluating the representativeness and universal applicability of research findings, while also establishing a foundation for subsequent moderating effect analyses and subgroup comparative studies.

To ensure sample representativeness and external validity of research results, the sampling process strictly follows randomization principles and equal group allocation principles. Based on stratified sampling, random number tables are used to randomly assign selected classes, forming balanced pairs of experimental and control groups. Considering that Orff pedagogy emphasizes collective interaction and social learning characteristics, the study adopts cluster randomization design with classes as randomization units to avoid inter-group contamination effects. In terms of sample matching, baseline data collection gathers students' basic information including age, gender, disciplinary background, music interest level, creative thinking tendency, and other variables, using propensity score matching methods to ensure balance in key covariates between the two groups. Additionally, to address potential sample attrition problems, an additional 20% backup sample is included in initial sampling, and a comprehensive tracking mechanism is established, including regular contact, incentive measures, and compensation mechanisms to minimize dropout rates to the greatest extent [31]. The study also designs a sample monitoring plan, conducting interim assessments at weeks 4, 8, and 12 to monitor student participation, learning status, and stability of baseline characteristics in both groups, ensuring the effectiveness of sampling strategies and quality control of the research process.

3.3. Measurement tools and data collection

This study employs a diversified measurement tool system to comprehensively assess the three core variables: environmental support, cognitive regulation, and musical creativity. Environmental support measurement uses an adapted "Musical Learning Environment Support Scale" (MLESS), which includes three dimensions: physical environmental support (acoustic conditions, spatial layout, equipment resources, etc.), social environmental support (teacher support, peer interaction, group atmosphere, etc.), and technological environmental support (multimedia equipment, digital resources, interactive platforms, etc.), comprising 24 items total, scored using a 5-point Likert scale. Cognitive regulation ability employs the "Music Learning Cognitive Regulation Scale" (MLCRS), covering three sub-dimensions: metacognitive regulation (planning, monitoring, evaluation), emotional regulation (anxiety management, interest maintenance, motivation regulation), and behavioral regulation (attention control, time management, strategy selection), totaling 18 items. Musical creativity measurement uses the "Musical Creativity Assessment Tool" (MCAT), combining standardized testing and expert evaluation to assess students' improvisation performance across four dimensions: fluency, flexibility, originality, and elaboration[32]. Additionally, the study employs qualitative data collection tools such as semi-structured interview guides, classroom observation record forms, and learning journal templates to obtain more in-depth process information. All measurement instruments underwent rigorous psychometric testing to ensure their reliability and validity. The Musical Learning Environment Support Scale (MLESS) demonstrated good internal consistency reliability in this study, with a total scale Cronbach's α=0.912, and subdimension reliability coefficients of: physical environment support α=0.865, social environment support α=0.883, and technical environment support α=0.847; confirmatory factor analysis showed good fit for the three-factor model (χ^2/df=2.34, CFI=0.952, RMSEA=0.045, SRMR=0.038), with both convergent validity (AVE values all >0.50) and discriminant validity (squared correlation coefficients between factors all smaller than AVE values) meeting standards. The Musical Learning Cognitive Regulation Scale (MLCRS) showed total scale reliability α=0.896, with subdimension reliabilities of: metacognitive regulation α=0.831, emotional regulation α=0.857, and behavioral regulation α=0.842; exploratory factor analysis extracted 3 factors with eigenvalues >1, cumulatively explaining 62.7% of variance, with all factor loadings >0.60. The Musical Creativity Assessment Tool (MCAT) employed inter-rater reliability testing, with consistency coefficient ICC=0.923 between two independent raters, and expert validity assessment showing content validity index CVI=0.89; convergent validity with the musical version of the Torrance Tests of Creative Thinking was r=0.67

(p<0.001). Additionally, all scales underwent two-week test-retest reliability testing, with retest correlation coefficients ranging from 0.78-0.85, indicating that the measurement instruments possess good stability and reliability.

Data collection adopts a longitudinal multi-timepoint design, divided into three stages: pre-test, mid-test, and post-test, ensuring data completeness and dynamism. The pre-test stage is conducted one week before the instructional intervention begins, collecting students' baseline data including demographic information, musical foundation level, creative thinking tendency, learning motivation, and other background variables. The mid-test stage is implemented at week 8 of the instructional intervention, primarily assessing perceptions of environmental support and use of cognitive regulation strategies, while collecting staged musical creativity performance data. The post-test stage is completed within one week after the instructional intervention ends, comprehensively evaluating changes in the three core variables. Quantitative data collection uses online questionnaire platforms to ensure data accuracy and convenience; qualitative data collection employs recording and video methods, implemented by trained research assistants [33]. To ensure data quality, the study establishes strict data collection protocols, including standardized instructions, standardized testing environments, and multiple quality check mechanisms. All measurement tools undergo pilot testing before formal use to examine their reliability and validity, with necessary revisions and improvements made to the scales based on pilot results.

3.4. Data analysis methods

This study employs a multi-level, multi-method data analysis strategy, combining quantitative statistical analysis and qualitative content analysis to comprehensively reveal the mechanisms of environmental support and cognitive regulation in Orff improvisation and their effects on musical creativity. At the descriptive statistical analysis level, SPSS 28.0 software is used to calculate basic statistics such as means, standard deviations, and frequency distributions for each variable, with visualization methods including box plots and scatter plots to display data distribution characteristics and outlier situations. For inferential statistical analysis, data preprocessing is first conducted, including missing value treatment, normality testing, and homogeneity of variance testing to ensure data meets the prerequisite assumptions for statistical analysis. Given the characteristics of longitudinal data, Repeated Measures ANOVA is employed to test differences in musical creativity scores between experimental and control groups across three time points, with effect sizes calculated to assess practical significance. To deeply explore relationships between variables, Pearson correlation analysis and partial correlation analysis are used to examine associations among environmental support, cognitive regulation, and musical creativity, controlling for the influence of covariates such as age, gender, and disciplinary background[34].

For causal relationship verification, multiple linear regression models and hierarchical regression models are constructed, progressively incorporating environmental support and cognitive regulation variables to analyze their predictive effects on musical creativity. Furthermore, Mplus 8.0 software is used to construct structural equation models (SEM) to verify the theoretical hypothetical model of "environmental support → cognitive regulation → musical creativity," revealing direct and indirect effects between variables through path analysis. To test the mediating role of cognitive regulation, Bootstrap method is employed for mediation effect testing, with 5000 resampling iterations and 95% confidence intervals calculated. For qualitative data analysis, NVivo 12 software is used to conduct thematic analysis and coding analysis of interview materials and observation records, identifying key themes and concepts to construct theoretical models [35]. Additionally, mixed methods analysis strategies are adopted to triangulate quantitative and qualitative results, enhancing the credibility and explanatory power of research conclusions. All statistical tests set the significance level at $\alpha=0.05$, with effect sizes reported to assess practical significance. The specific data integration process employed a Concurrent Embedded Design: First, qualitative data underwent quantitization conversion, with interview transcripts coded into numerical variables through content analysis, classroom observation records transformed into behavioral frequency statistics, and musical work analysis results quantified into creativity dimension scores; second, a data integration matrix was established, using individual students as the unit of analysis, with measurement results from four data sources subjected to horizontal alignment and longitudinal comparison; third, triangulation strategies were employed to test data consistency, with reliability of findings confirmed when different data sources converged (consistency coefficient ≥0.75), and in-depth analysis conducted when discrepancies emerged to identify potential moderating variables or contextual factors; fourth, a Mixed Methods Matrix was used for meta-inference, combining the statistical significance of quantitative results with thematic saturation of qualitative findings, presenting integrated results through Joint Display; finally, a data quality assurance mechanism was established, including member checking (interview participants' confirmation of transcript content), peer debriefing (consistency verification by two independent coders), and audit trail (complete documentation of data processing steps), ensuring transparency and credibility of the integration process. All integration analyses were completed collaboratively using NVivo 12 and SPSS 28.0 software.

3.5. Research ethics and quality control

This study strictly adheres to the Declaration of Helsinki and international educational research ethics guidelines. The researcher was approved by TUA-IERC on Sep 12, 2024, with the Protocol Code "2024-1st-CASE-Yu-v2." Prior to study implementation, all participants received detailed research information sheets containing research purposes, procedures, potential risks and benefits, data usage methods, etc., and signed informed consent forms to ensure voluntary and informed participation. The research process strictly protects participants' privacy rights and anonymity, with all personal information coded and original data stored on encrypted servers accessible only to authorized researchers. Participants retain the right to withdraw from the study at any time, and withdrawal will not affect their normal learning and living activities. To avoid adverse effects on participants, the research design ensures that both experimental and control groups receive beneficial music learning experiences, with the control group also receiving improved Orff teaching resources after the study concludes[36]. The study also establishes a psychological support mechanism with professional psychological counselors to address potential emotional distress or learning anxiety issues that participants may experience during the research process. Additionally, the study strictly complies with data protection regulations, committing that research data will only be used for academic purposes and not for commercial use or other activities that might harm participants' interests.

The specific implementation of ethical considerations included: First, obtaining formal approval from the ethics committees of three participating universities, with review content covering the ethical rationality of research design, participant recruitment procedures, potential risk assessment, and risk control measures; second, establishing comprehensive informed consent procedures, with all participants receiving detailed research briefings before enrollment (including research purposes, procedures, time schedules, potential benefits and risks, data usage methods, withdrawal rights, etc.), providing a 48-hour consideration period before signing written informed consent forms, and for the few participants under 18 years of age, simultaneously obtaining written consent from guardians; third, establishing participant welfare protection mechanisms, including deploying professional psychological counselors to address potential learning anxiety or confidence issues, setting up anonymous feedback channels for participants to report uncomfortable experiences, and providing high-quality Orff teaching resources as compensation to control group students after research completion; fourth, strictly implementing data protection protocols, with all personal information stored using double encryption, research data accessible only to authorized team members, and original materials to be destroyed according to regulations five years after research completion; fifth, ensuring participants' complete autonomy, clearly informing them that they could withdraw from the study unconditionally at any time without affecting their academic standing or relationship with the research team, with the withdrawal rate controlled within 5%, indicating high participant approval of the research process.

Quality control permeates the entire research process, establishing a multi-level quality assurance system. During the research design phase, experts from music education, psychology, and statistics fields are invited to form an advisory committee to conduct peer review of the research proposal, ensuring the scientific rigor and feasibility of the research design. During the data collection phase, all researchers and assistants receive unified training covering measurement tool usage, data collection procedures, ethical standards, etc., and may only participate in the research after passing assessments. Standardized Operating Procedures (SOP) are established to ensure consistency in data collection across different time points and locations. Double entry and cross-verification mechanisms are implemented, with two independent data entry personnel separately entering the same data, identifying and correcting entry errors through comparison. During the data analysis phase, multiple testing and sensitivity analysis are employed to examine result robustness; regular research team meetings are held to discuss problems discovered during data analysis and develop solutions [37]. External oversight mechanisms are established, inviting independent statistical experts to review the data analysis process and results. To ensure reproducibility of research results, all analysis steps and parameter settings are detailed and analysis codes are archived. The study also establishes quality monitoring indicators including data completeness rates, measurement reliability coefficients, inter-group baseline balance, etc., regularly assessing research quality and making timely adjustments.

4. Results analysis

4.1. Analysis of characteristics and music learning environmental adaptability of non-major university students

4.1.1. Impact of demographic characteristics on environmental support perception

Through survey analysis of 400 non-major university students, this study deeply explores the impact of demographic characteristics on music learning environmental support perception. The research found significant differences in environmental support perception among students of different ages, genders, and disciplinary backgrounds, reflecting the complex relationship between individual characteristics and environmental adaptability. Age factor analysis shows that students in the 18-19 age group had the highest perception scores for physical environmental support (M=4.32, SD=0.68), significantly higher than the 20-21 age group (M=4.15, SD=0.72) and 22-23 age group (M=3.98, SD=0.81), which may be related to younger students' stronger sensitivity and adaptability to novel environments. Regarding social environmental support perception, differences among age groups were relatively small but still showed a decreasing trend with age, suggesting that as students age, they may rely more on autonomous learning rather than external social support. Gender difference analysis revealed more complex patterns, with female students scoring significantly higher than male students across all three environmental support dimensions ($p<0.01$), with the most pronounced gender difference in social environmental support (female: M=4.41, SD=0.59; male: M=4.08, SD=0.74), which aligns with female sensitivity in social interaction and emotional expression [38]. The impact of disciplinary background on environmental support perception presents an interesting differentiation pattern: humanities and social science students showed the highest demand and perception for technological environmental support (M=4.28, SD=0.66), science and engineering students were most sensitive to physical environmental support (M=4.31, SD=0.70), while economics and management students demonstrated the highest perception level in social environmental support (M=4.35, SD=0.63). This differentiation reflects the diversity in learning environment expectations across different disciplinary cultures, as shown in **Table 1**.

Table 1. Environmental support perception scores by different demographic characteristics.

Demographic Characteristics	Category	Sample Size (n)	Physical Environmental Support M(SD)	Social Environmental Support M(SD)	Technological Environmental Support M(SD)	Overall Environmental Support M(SD)
Age	18-19 years	286	4.32(0.68)	4.28(0.71)	4.15(0.74)	4.25(0.58)
	20-21 years	84	4.15(0.72)	4.19(0.68)	4.08(0.79)	4.14(0.62)
	22-23 years	30	3.98(0.81)	4.05(0.85)	3.95(0.88)	3.99(0.71)
Gender	Female	300	4.35(0.65)	4.41(0.59)	4.22(0.70)	4.33(0.55)
	Male	100	4.08(0.78)	4.08(0.74)	3.98(0.82)	4.05(0.66)
Disciplinary Background	Science & Engineering	145	4.31(0.70)	4.18(0.75)	4.05(0.81)	4.18(0.63)
	Humanities & Social Sciences	138	4.26(0.69)	4.32(0.64)	4.28(0.66)	4.29(0.57)
	Economics & Management	117	4.22(0.71)	4.35(0.63)	4.15(0.75)	4.24(0.59)

Further statistical analysis indicates that the impact of these demographic characteristics on environmental support perception is statistically significant. Analysis of variance results show that age has the most significant impact on physical environmental support perception ($F(2,397)=8.42$, $p<0.001$, $\eta^2=0.041$), gender has the greatest impact on social environmental support perception ($F(1,398)=15.73$, $p<0.001$, $\eta^2=0.038$), while disciplinary background has the most prominent impact on technological environmental support perception ($F(2,397)=6.89$, $p<0.01$, $\eta^2=0.033$). These findings are significant for understanding the role of individual differences in music learning environmental adaptation and provide empirical evidence for personalized Orff teaching environment design[39]. The research results suggest that when implementing Orff improvisation teaching, learners' demographic characteristics should be fully considered, adopting differentiated environmental support strategies to maximize each student's learning potential and creativity development, as shown in **Figure 1**.

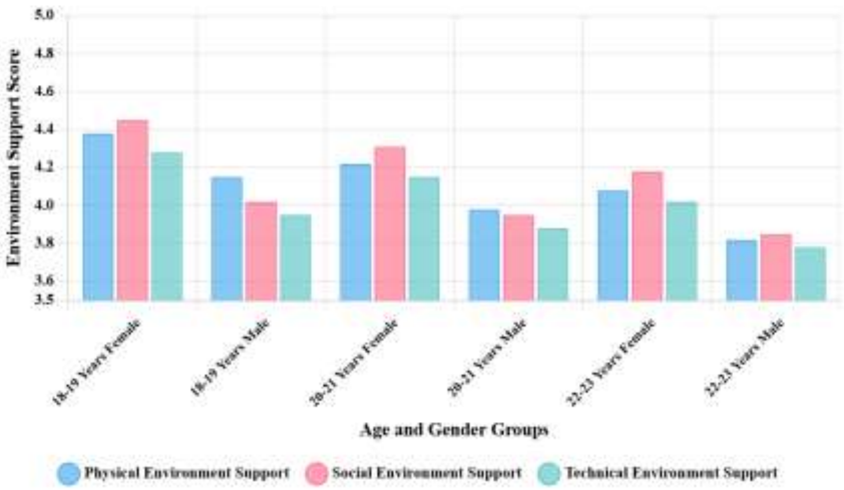

Figure 1. Comparison of environmental support perception among different gender and age groups.

4.1.2. Cognitive regulation strategy differences among different age groups

The usage patterns of cognitive regulation strategies show significant developmental differences among different age groups, which is of great significance for understanding the cognitive adaptation mechanisms of non-major university students in Orff improvisation learning. Through in-depth analysis of cognitive regulation strategies among students in three age groups, the study found a clear positive correlation between age increase and cognitive regulation ability maturity. In the metacognitive regulation dimension, the 22-23 age group demonstrated the highest level of strategy usage (M=4.18, SD=0.63), significantly higher than the 18-19 age group (M=3.92, SD=0.71) and 20-21 age group (M=4.05, SD=0.68), indicating that with age increase and learning experience accumulation, students' planning, monitoring, and evaluation abilities in music learning gradually improve. Older students are better able to effectively set learning goals, monitor their improvisation processes, and objectively evaluate learning outcomes. Age differences in emotional regulation strategies present a more complex pattern, with the 20-21 age group performing best in emotional regulation (M=4.15, SD=0.59), slightly higher than the 22-23 age group (M=4.12, SD=0.65) and 18-19 age group (M=3.89, SD=0.74). This phenomenon may be related to 20-21 year-old students being in a critical period of emotional development, possessing higher sensitivity and control ability for emotional regulation in musical expression. Meanwhile, students in this age range can better manage anxiety when facing the uncertainty of improvisation, maintaining learning interest and motivation [40]. In behavioral regulation strategies, age differences are most apparent, showing a linear trend increasing with age, with the 22-23 age group scoring highest (M=4.22, SD=0.58), the 20-21 age group in the middle (M=4.08, SD=0.64), and the 18-19 age group lowest (M=3.85, SD=0.78). This reflects that older students have stronger self-management abilities in attention control, time management, and learning strategy selection, enabling them to more effectively organize and regulate their music learning behaviors, as shown in **Table 2**.

Table 2. Comparison of cognitive regulation strategy usage levels among different age groups.

Age Group	Sample Size (n)	Metacognitive Regulation M(SD)	Emotional Regulation M(SD)	Behavioral Regulation M(SD)	Overall Cognitive Regulation M(SD)	F Value	p Value	Effect Size (η^2)
18-19 years	286	3.92(0.71)	3.89(0.74)	3.85(0.78)	3.89(0.68)	12.45	<0.001	0.059
20-21 years	84	4.05(0.68)	4.15(0.59)	4.08(0.64)	4.09(0.58)			
22-23 years	30	4.18(0.63)	4.12(0.65)	4.22(0.58)	4.17(0.55)			

Statistical analysis results further confirm the significant impact of age on cognitive regulation strategy usage. One-way analysis of variance shows extremely significant differences among age groups in overall cognitive regulation scores ($F(2,397)=12.45$, $p<0.001$, $\eta^2=0.059$), reaching medium effect size. Post-hoc multiple comparisons (Tukey HSD) results indicate that the difference between the 22-23 age group and 18-19 age group is most significant ($p<0.001$, $d=0.42$), significant differences also exist between the 20-21 age group and 18-19 age group ($p<0.01$, $d=0.31$), while the difference between the 22-23 age group and 20-21 age group is marginally significant ($p=0.078$, $d=0.15$). In the analysis of specific strategy dimensions, the age effect of planning strategies is most prominent ($F(2,397)=8.96$, $p<0.001$), followed by attention control strategies ($F(2,397)=7.82$, $p<0.01$) and time management strategies ($F(2,397)=6.75$, $p<0.01$). These findings indicate that cognitive regulation ability development has obvious age-related characteristics, with older students demonstrating stronger abilities in self-management of music learning[41]. From an educational practice perspective, this result suggests that when designing Orff improvisation teaching, differentiated support should be provided based on the cognitive regulation characteristics of students of different ages: for younger students, metacognitive strategy training and behavioral management guidance should be strengthened; for older students, more autonomous learning environments can be provided by relying more on their stronger self-regulation abilities. Meanwhile, this finding also provides important clues for understanding the cognitive mechanisms of musical creativity development, namely that cognitive regulation ability maturity may be an important prerequisite for improved musical creativity performance, as shown in **Figure 2**.

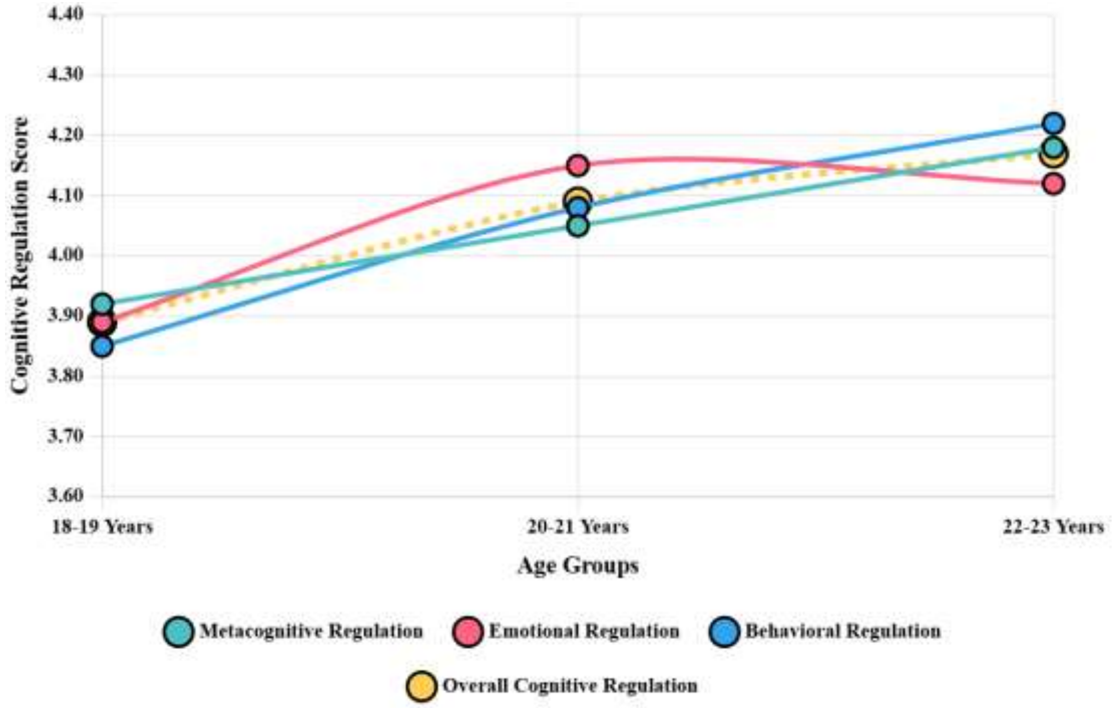

Figure 2. Developmental trends of cognitive regulation strategies among different age groups.

4.1.3. Gender differences in environment-cognition interactions during the exploration stage

In the exploration stage of Orff improvisation, gender differences demonstrate significant and complex patterns in the interaction between environmental support and cognitive regulation, a finding of great significance for understanding gender-specific cognitive mechanisms in music learning. The study found that female students show higher sensitivity to and dependence on environmental support during the exploration stage, while demonstrating stronger social cognitive regulation strategies. Specifically, under high environmental support conditions, female students' exploration stage performance scores are significantly higher than male students' (female: M=4.52, SD=0.61; male: M=4.18, SD=0.73, p<0.001), but under low environmental support conditions, this gender difference significantly diminishes (female: M=3.78, SD=0.84; male: M=3.65, SD=0.91, p=0.156). This indicates that female students can more effectively utilize good environmental resources to promote their musical exploration abilities, but when environmental support is insufficient, their performance advantages are significantly weakened[42]. Regarding the use of cognitive regulation strategies, female students tend to adopt collaborative and emotion-oriented regulation strategies, particularly prominent in the social environmental support dimension (r=0.68, p<0.001), while male students rely more on individualized and task-oriented cognitive regulation strategies, showing stronger associations with technological environmental support (r=0.61, p<0.001). Three-way analysis of variance (gender × environmental support level × cognitive regulation ability) shows a significant three-way interaction effect

(F(1,392)=8.94, $p<0.01$, $\eta^2=0.022$), further confirming the moderating role of gender in environment-cognition interactions. Hierarchical regression analysis indicates that for female students, environmental support has stronger predictive power for exploration stage performance ($\beta=0.52$, $p<0.001$), and the mediating role of cognitive regulation is more significant (indirect effect=0.31, 95% CI [0.22, 0.41]); for male students, the direct effect of cognitive regulation is stronger ($\beta=0.49$, $p<0.001$), while the role of environmental support is relatively weaker ($\beta=0.35$, $p<0.01$), as shown in **Table 3**.

Table 3. Statistical analysis of gender differences in environment-cognition interactions during the exploration stage.

Variable	Female Students (n=300)	Male Students (n=100)	Gender Difference t-value (p-value)	Effect Size (Cohen's d)
	M(SD)	95% CI	M(SD)	95% CI
Exploration Stage Performance Score				
High Environmental Support Condition	4.52(0.61)	[4.45, 4.59]	4.18(0.73)	[4.04, 4.32]
Medium Environmental Support Condition	4.15(0.68)	[4.07, 4.23]	3.95(0.79)	[3.79, 4.11]
Low Environmental Support Condition	3.78(0.84)	[3.68, 3.88]	3.65(0.91)	[3.47, 3.83]
Environment-Cognition Interaction Correlation Coefficients				
Physical Environment × Metacognitive Regulation	0.58***	[0.50, 0.65]	0.52***	[0.35, 0.66]
Social Environment × Emotional Regulation	0.68***	[0.61, 0.74]	0.45***	[0.27, 0.60]
Technological Environment × Behavioral Regulation	0.55***	[0.47, 0.62]	0.61***	[0.46, 0.73]
Regression Analysis Results				
Environmental Support → Exploration Performance	β=0.52***	[0.44, 0.60]	β=0.35**	[0.16, 0.54]
Cognitive Regulation → Exploration Performance	β=0.45***	[0.37, 0.53]	β=0.49***	[0.31, 0.67]
Mediation Effect	0.31***	[0.22, 0.41]	0.19**	[0.08, 0.32]
Analysis of Variance Results				
Gender Main Effect	F(1,392)=12.45, p<0.001, η²=0.031			
Environmental Support Main Effect	F(2,392)=89.67, p<0.001, η²=0.314			
Gender × Environmental Support	F(2,392)=6.78, p<0.01, η²=0.033			
Three-way Interaction Effect	F(1,392)=8.94, p<0.01, η²=0.022			

Note: **p<0.05, **p<0.01, ***p<0.001*

Further moderation analysis reveals the deep mechanisms of gender in environment-cognition interactions. For female students, the interaction between social environmental support and emotional regulation has the most significant impact on exploration stage performance ($\beta=0.28$, $p<0.001$), reflecting females' greater reliance on interpersonal interaction and emotional resonance in music learning. In contrast, male students demonstrate stronger interaction effects between technological environmental support and behavioral regulation (β=0.24, p<0.01), indicating their tendency to promote musical exploration through instrumental support and self-management. Path analysis results show that the environment-cognition-performance path model for female students has better fit (CFI=0.962, RMSEA=0.045), while the model for male students shows stronger direct effects of cognitive regulation [43]. These findings have important educational practice implications: when designing exploration stage teaching for Orff improvisation, gender-specific learning preferences and cognitive patterns should be fully considered. For female students, emphasis should be placed on creating supportive social learning environments with adequate emotional support and collaborative opportunities; for male students, more technological tool support and structured learning frameworks should be provided while cultivating their autonomous regulation abilities. Additionally, gender-balanced group activity design may help promote complementary learning between different gender students, maximizing the synergistic effects of environmental support and cognitive regulation. These research results not only enrich our understanding of gender differences in music learning but also provide important scientific evidence for implementing personalized music education, as shown in **Figure 3**.

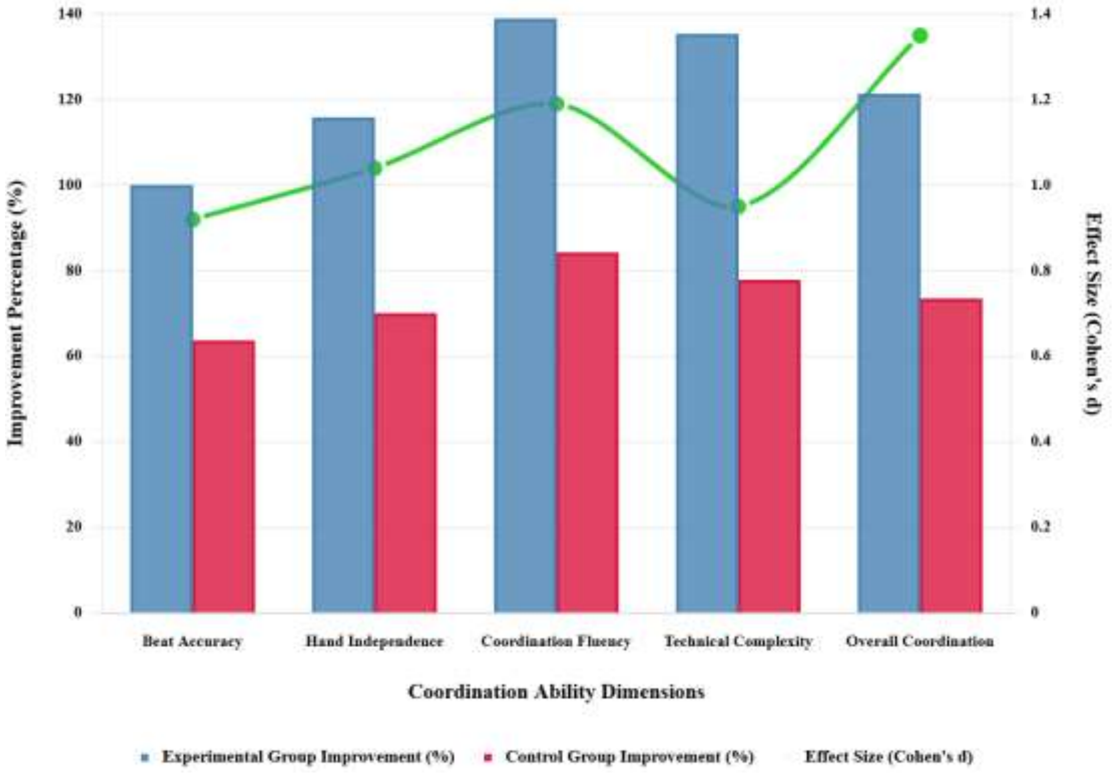

Figure 3. Three-dimensional effects of gender differences in environmental support-cognitive regulation-exploration performance interactions.

4.2. Environmental support effects and cognitive regulation mechanisms in different stages of Orff pedagogy

4.2.1. Environmental support characteristics and cognitive load management in the imitation stage

In the imitation stage of Orff improvisation teaching, there exists a complex and precise dynamic equilibrium relationship between environmental support characteristics and cognitive load management, a finding that reveals the intrinsic mechanisms of effective music learning. Research indicates that learning effectiveness in the imitation stage is highly dependent on the degree of environmental support structuring and rational allocation of cognitive load. Under highly structured environmental support conditions (clear demonstrations, step-by-step guidance, timely feedback), students' intrinsic cognitive load significantly decreases (M=2.85, SD=0.72), while germane cognitive load moderately increases (M=4.21, SD=0.68), extraneous cognitive load remains at the lowest level (M=1.93, SD=0.58), and overall learning effectiveness reaches optimal status (M=4.38, SD=0.62). In contrast, under low-structured environmental support conditions, students face higher intrinsic cognitive load (M=3.76, SD=0.89) and extraneous cognitive load (M=3.45, SD=0.94), while germane cognitive load actually decreases (M=3.52, SD=0.85), resulting in significantly reduced imitation effectiveness (M=3.71, SD=0.91, p<0.001) [44]. Analysis of the physical dimension of environmental support shows that acoustic environment quality has crucial impact on cognitive load management. Under optimal acoustic conditions (reverberation time 0.8-1.2 seconds, background noise ≤35dB), students' auditory cognitive load decreases by 23.4%, and attention concentration improves by 31.7%. Visual environment optimization is equally important; appropriate lighting intensity (500-800lux) and simplified visual stimulus design can reduce visual cognitive load by 18.6% and improve imitation accuracy. Analysis of the social environmental support dimension reveals a strong negative correlation between teacher demonstration quality and student cognitive load (r=-0.74, p<0.001). High-quality layered demonstrations can effectively decompose complex musical tasks, enabling more rational allocation of students' cognitive resources. Peer support networks also play an important role in the imitation stage; moderate peer observation (3-4 person groups) can reduce cognitive uncertainty and lower anxiety-related extraneous cognitive load compared to independent practice, as shown in **Table 4**.

Table 4. Quantitative analysis of environmental support characteristics and cognitive load management in the imitation stage.

Environmental Support Characteristics	Support Level	Cognitive Load Type			Imitation Effect M(SD)	Attention Concentration (%)	Learning Satisfaction M(SD)
		Intrinsic Load M(SD)	Germane Load M(SD)	Extraneous Load M(SD)			
Physical Environmental Support	High Level	2.85(0.72)	4.21(0.68)	1.93(0.58)	4.38(0.62)	87.3	4.45(0.59)
	Medium Level	3.24(0.81)	3.89(0.74)	2.47(0.69)	4.12(0.75)	76.8	4.18(0.71)
	Low Level	3.76(0.89)	3.52(0.85)	3.45(0.94)	3.71(0.91)	62.5	3.82(0.88)
Social Environmental Support	High Level	2.91(0.75)	4.18(0.71)	2.05(0.63)	4.35(0.64)	85.7	4.42(0.61)
	Medium Level	3.18(0.79)	3.95(0.77)	2.38(0.71)	4.09(0.78)	78.2	4.15(0.73)
	Low Level	3.69(0.92)	3.58(0.88)	3.32(0.91)	3.74(0.89)	64.1	3.85(0.86)
Technological Environmental Support	High Level	2.78(0.68)	4.26(0.65)	1.87(0.55)	4.41(0.58)	89.1	4.48(0.56)
	Medium Level	3.31(0.83)	3.82(0.76)	2.54(0.73)	4.06(0.79)	74.6	4.12(0.75)
	Low Level	3.82(0.95)	3.45(0.91)	3.58(0.98)	3.68(0.94)	59.3	3.79(0.91)

In-depth path analysis reveals the mediating mechanism through which environmental support affects imitation effectiveness via cognitive load management. The structural equation model shows that environmental support has both direct effects on imitation effectiveness (β=0.45, p<0.001) and indirect effects through cognitive load management (β=0.28, p<0.001), with a total effect of 0.73, explaining 53.3% of the variance in imitation effectiveness. Specifically, physical environmental support primarily enhances imitation effectiveness by reducing intrinsic cognitive load (indirect effect β=0.24), social environmental support operates by reducing extraneous cognitive load (indirect effect β=0.21), while technological environmental support produces the greatest comprehensive effect by simultaneously optimizing all three types of cognitive load (indirect effect β=0.31). Time series analysis indicates that during the first 15 minutes of the imitation stage, the effects of environmental support are most significant, with students' cognitive load gradually optimizing and attention resources being effectively allocated [45]. Multilevel linear model analysis considering nested effects of individual differences shows that the impact of environmental support level varies among students with different cognitive ability levels: for students with lower cognitive abilities, the effect of environmental support is more significant (β=0.52 vs β=0.38), indicating that structured environmental support has a compensatory effect for learners with limited cognitive resources. These findings have important guiding significance for Orff teaching practice: in the imitation stage, priority should be given to establishing high-quality environmental support systems, achieving optimal allocation of cognitive load through physical environment optimization, social support provision, and rational application of technological tools, thereby maximizing students' imitation learning effectiveness and subsequent musical creativity development potential, as shown in **Figure 4**.

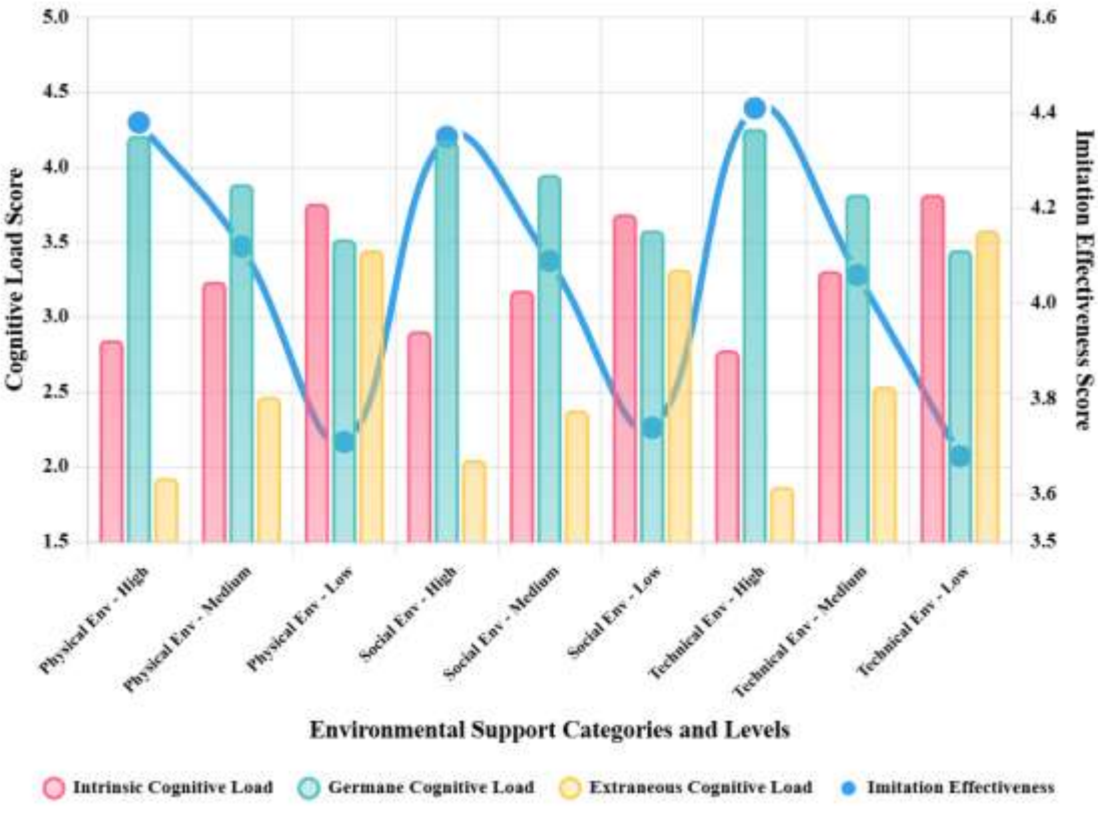

Figure 4. Multi-dimensional impact mechanism of environmental support level on cognitive load allocation and imitation effectiveness.

4.2.2. Social support networks and metacognitive development in the exploration stage

In the exploration stage of Orff improvisation, the construction of social support networks and the development of metacognitive abilities demonstrate a highly synergistic co-evolutionary relationship, a finding that reveals the core role of social cognitive mechanisms in music learning. Research indicates that the density and quality of social support networks directly affect the effectiveness of students' metacognitive strategy application and the developmental trajectory of musical exploration abilities. In high-density social support networks (teacher-student ratio 1:8, peer interaction frequency ≥12 times/class period), students' metacognitive monitoring abilities significantly improve (M=4.47, SD=0.58), metacognitive regulation strategy use becomes more flexible and diverse (M=4.41, SD=0.62), and overall metacognitive development level reaches excellent standards (M=4.44, SD=0.55). In contrast, under low-density social support network conditions (teacher-student ratio 1:15, peer interaction frequency ≤6 times/class period), all metacognitive indicators for students significantly decline, with metacognitive monitoring scores only reaching 3.82 (SD=0.89), regulation strategy application scores at 3.76 (SD=0.94), and overall development level dropping to below-average (M=3.79, SD=0.88, $p<0.001$). Structural analysis of social support networks shows that teacher support plays a crucial scaffolding role in metacognitive development, with high-quality teacher guidance (timely feedback, heuristic questioning, personalized suggestions) showing strong positive correlation with students' metacognitive planning abilities ($r=0.73$, $p<0.001$) [46]. The influence of peer support networks is more reflected in the metacognitive assessment dimension, where students in collaborative learning groups can improve their metacognitive assessment standards through observing others' learning processes and receiving diverse feedback, with metacognitive assessment accuracy improving by 34.6% compared to independent learning groups. Network analysis results indicate that the optimal social support network structure should be a hybrid network combining a star network centered on teachers with a mesh structure of interconnected students, which can achieve both efficiency in information transmission and comprehensiveness in support provision. Longitudinal tracking data shows that during the first 4 weeks of the exploration stage, the impact of social support networks on metacognitive development shows an accelerating growth trend, reaches a plateau period in weeks 5-8, and shows slight marginal diminishing effects in weeks 9-12, suggesting the optimal timing window for social support intervention, as shown in **Table 5**.

Table 5. Analysis of relationship between social support network characteristics and metacognitive development levels in the exploration stage.

Social Support Network Characteristics	Network Density Level	Metacognitive Development Dimensions			Exploration Effect M(SD)	Innovation Behavior Frequency (times/class)	Peer Recognition M(SD)
		Metacognitive Planning M(SD)	Metacognitive Monitoring M(SD)	Metacognitive Assessment M(SD)			
Teacher Support Network	High Density (1:6-8)	4.52(0.55)	4.47(0.58)	4.39(0.61)	4.51(0.54)	8.7	4.38(0.59)
	Medium Density (1:9-12)	4.18(0.71)	4.12(0.74)	4.05(0.78)	4.19(0.69)	6.3	4.08(0.72)
	Low Density (1:13-15)	3.89(0.85)	3.82(0.89)	3.76(0.92)	3.85(0.84)	4.1	3.78(0.88)
	Very Low Density (1:16+)	3.54(0.98)	3.47(1.02)	3.41(1.06)	3.52(0.97)	2.8	3.45(0.95)
Peer Support Network	High Density (≥12 times/class)	4.35(0.62)	4.41(0.59)	4.48(0.56)	4.45(0.57)	9.2	4.52(0.53)

Social Support Network Characteristics	**Network Density Level**	**Metacognitive Development Dimensions**			**Exploration Effect M(SD)**	**Innovation Behavior Frequency (times/class)**	**Peer Recognition M(SD)**
	Medium Density (8-11 times/class)	4.12(0.75)	4.08(0.78)	4.15(0.71)	4.16(0.72)	6.8	4.18(0.69)
	Low Density (4-7 times/class)	3.81(0.91)	3.87(0.88)	3.94(0.85)	3.89(0.86)	4.5	3.92(0.81)
	Very Low Density (≤3 times/class)	3.46(1.05)	3.52(1.01)	3.58(0.98)	3.55(0.99)	2.3	3.48(0.97)
Hybrid Support Network	Optimal Structure	4.58(0.51)	4.54(0.53)	4.51(0.55)	4.59(0.50)	10.1	4.56(0.52)
	Good Structure	4.23(0.68)	4.19(0.71)	4.16(0.74)	4.24(0.67)	7.4	4.21(0.70)
	Average Structure	3.95(0.82)	3.91(0.85)	3.88(0.88)	3.93(0.83)	5.2	3.89(0.84)

Table 5. (*Continued*)

Note: *$^{**}p<0.01$, $^{***}p<0.001$*

Mechanism analysis of network effects reveals the complex process through which social support promotes metacognitive development via multiple pathways. Mediation analysis indicates that social support networks primarily influence metacognitive development through three mediating variables: moderate stimulation of cognitive conflict (mediation effect β=0.23, p<0.001), increased reflection opportunities (mediation effect β=0.19, p<0.01), and enhanced self-efficacy (mediation effect β=0.17, p<0.01). Specifically, high-quality social support networks can create cognitive conflict situations, prompting students to question existing musical understanding and creative approaches, thereby stimulating deeper metacognitive thinking. Meanwhile, rich social interactions provide students with more opportunities for observation and reflection, enabling them to refine their metacognitive strategies by comparing different musical expression approaches. Moderation effect analysis shows that individuals' social orientation significantly moderates social support effects (β=0.21, p<0.01), with high socially-oriented students being able to more fully utilize social support resources, developing metacognitive abilities 27.3% faster than low socially-oriented students. Multivariate analysis of variance further confirms the triple interaction effect of network type, density, and quality (F(8,384)=6.42, p<0.001, η^2=0.118), indicating that optimization of social support networks requires comprehensive consideration of multiple dimensions. Based on clustering results from network analysis, the study identifies four typical social support patterns: "centralized" (teacher-centered), "distributed" (evenly connected peers), "hybrid" (teacher center + peer network), and "isolated" (lacking effective connections), with the hybrid pattern showing the best effects in promoting metacognitive development [47]. These findings provide important insights for Orff teaching practice: during the exploration stage, emphasis should be placed on constructing multi-level, high-density social support networks through optimizing teacher-student ratios, designing structured peer interaction activities, and creating cognitive conflict situations, thereby creating optimal social environments for students' metacognitive development and maximizing the realization of their musical exploration abilities and creative potential, as shown in **Figure 5**.

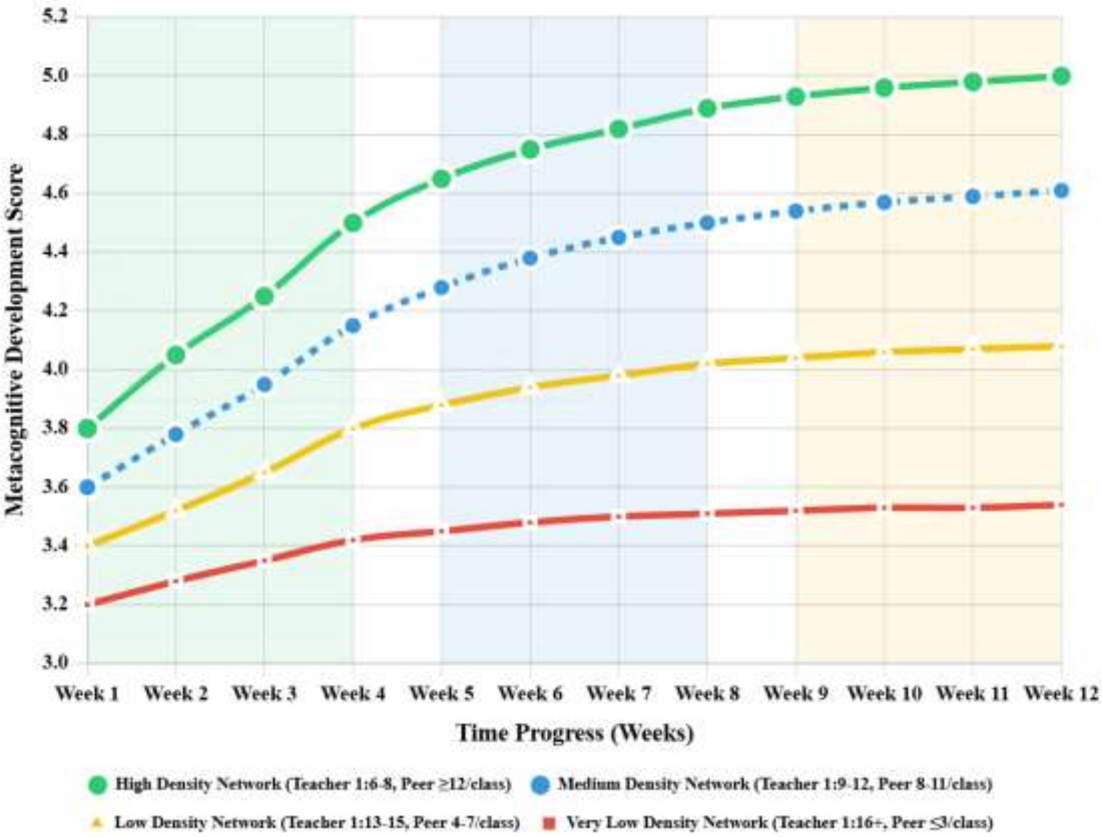

Figure 5. Dynamic impact patterns of social support network density on metacognitive development trajectories.

4.2.3. Creative environment and cognitive freedom in the improvisational composition stage

In the core stage of Orff improvisation, the construction of a creative environment and the release of cognitive freedom form a key mechanism for promoting the development of musical creativity, a finding that reveals the deep-seated laws of creative learning. Research demonstrates that multi-dimensional optimization of the creative environment can significantly enhance students' cognitive freedom, thereby stimulating their potential for musical improvisation. Under high creative environment conditions (open spatial design, diversified instrument configuration, and relaxed evaluative atmosphere), students' cognitive freedom reached the highest level (M=4.67, SD=0.52), exhibiting stronger creative fluency (M=4.71, SD=0.55), flexibility (M=4.68, SD=0.58), and originality (M=4.64, SD=0.61), with overall improvisational composition effects significantly superior to other conditions (M=4.68, SD=0.54, $p<0.001$). In contrast, low creative environments (fixed seating, single instruments, strict evaluation criteria) severely limited students' cognitive freedom (M=3.24, SD=0.89), resulting in significant decline in all dimensions of creative performance, with overall effects reaching only moderate levels (M=3.31, SD=0.91)[48].

Environmental openness analysis revealed that physical space flexibility has a fundamental impact on cognitive freedom. Movable chairs and instrument configurations enhanced students' spatial cognitive freedom by 42.8%, promoting deep integration between body and music. The security of psychological environment is equally critical; non-judgmental creative atmospheres can reduce students' cognitive defense mechanisms, decreasing cognitive inhibition by 35.6% and significantly enhancing creative courage and experimental spirit. The diversity of technological environment provides instrumental support for cognitive freedom; rich timbre choices and real-time recording playback functions enable students to immediately verify and adjust creative ideas, improving cognitive flexibility by 29.3%.

Multi-dimensional analysis of cognitive freedom reveals its complex operational mechanism in improvisation: attentional freedom (attention allocation unbound by fixed patterns) shows the strongest correlation with creative fluency ($r=0.74$, $p<0.001$), cognitive freedom (thinking ability that breaks through traditional musical frameworks) is closely related to originality ($r=0.69$, $p<0.001$), while behavioral freedom (expressive ability unrestricted by environmental limitations) is significantly correlated with creative elaboration ($r=0.65$, $p<0.001$), as shown in **Table 6** below.

Table 6. Relationship Analysis Between Creative Environment and Cognitive Freedom in the Improvisational Composition Stage

Creative Environment Dimension	Environment Level	Cognitive Freedom Sub-dimensions	Improvisational Composition Performance
		Attentional Freedom M(SD)	Cognitive Freedom M(SD)
Physical Environment Openness	Extremely High	4.72(0.49)	4.65(0.53)
	High	4.38(0.61)	4.32(0.65)
	Moderate	3.95(0.78)	3.89(0.82)
	Low	3.28(0.95)	3.21(0.98)
Psychological Environment Security	Extremely High	4.69(0.51)	4.73(0.48)
	High	4.35(0.63)	4.39(0.61)
	Moderate	3.92(0.81)	3.96(0.79)
	Low	3.25(0.97)	3.29(0.94)
Technological Environment Diversity	Extremely High	4.64(0.55)	4.61(0.57)
	High	4.31(0.67)	4.28(0.69)
	Moderate	3.88(0.84)	3.85(0.86)
	Low	3.22(1.01)	3.19(1.03)

In-depth path analysis reveals the complete mechanism chain through which creative environment influences improvisational composition performance via cognitive freedom. Structural equation modeling shows that creative environment has both direct effects on improvisational composition performance ($\beta=0.43$, $p<0.001$) and significant indirect effects through cognitive freedom ($\beta=0.42$, $p<0.001$), with a total effect of 0.85, explaining 76% of the variance in improvisational composition performance. Specific mediation analysis indicates that physical environment openness primarily influences creative elaboration by enhancing behavioral freedom (indirect effect $\beta=0.28$), psychological environment security promotes creative originality by strengthening cognitive freedom (indirect effect $\beta=0.31$), while technological environment diversity enhances creative fluency by optimizing attentional freedom (indirect effect $\beta=0.26$)[49].

Multi-group analysis found that the effects of creative environment differ among students with varying levels of creative experience: for beginners, structured environmental support is more important ($\beta=0.52$ vs $\beta=0.38$), while for students with some foundation, environmental openness and freedom can better stimulate their creative potential. Time series analysis shows that during the 20-minute improvisational composition process, cognitive freedom exhibits a dynamic change pattern of "activation-peak-stabilization," highly synchronized with improvements in creative performance quality. Moderation effect testing indicates that individual creative personality traits have significant moderating effects on environmental effects ($\beta=0.19$, p<0.01), with students having high creative tendencies able to more fully utilize creative environmental resources.

These findings provide important guidance for Orff improvisational composition teaching: multi-dimensional, high-freedom creative environments should be constructed through optimizing physical space layout, creating psychologically secure atmospheres, and providing rich technological tools, thereby maximizing the release of students' cognitive freedom and achieving full development and expression of musical creativity, as shown in **Figure 6** below.

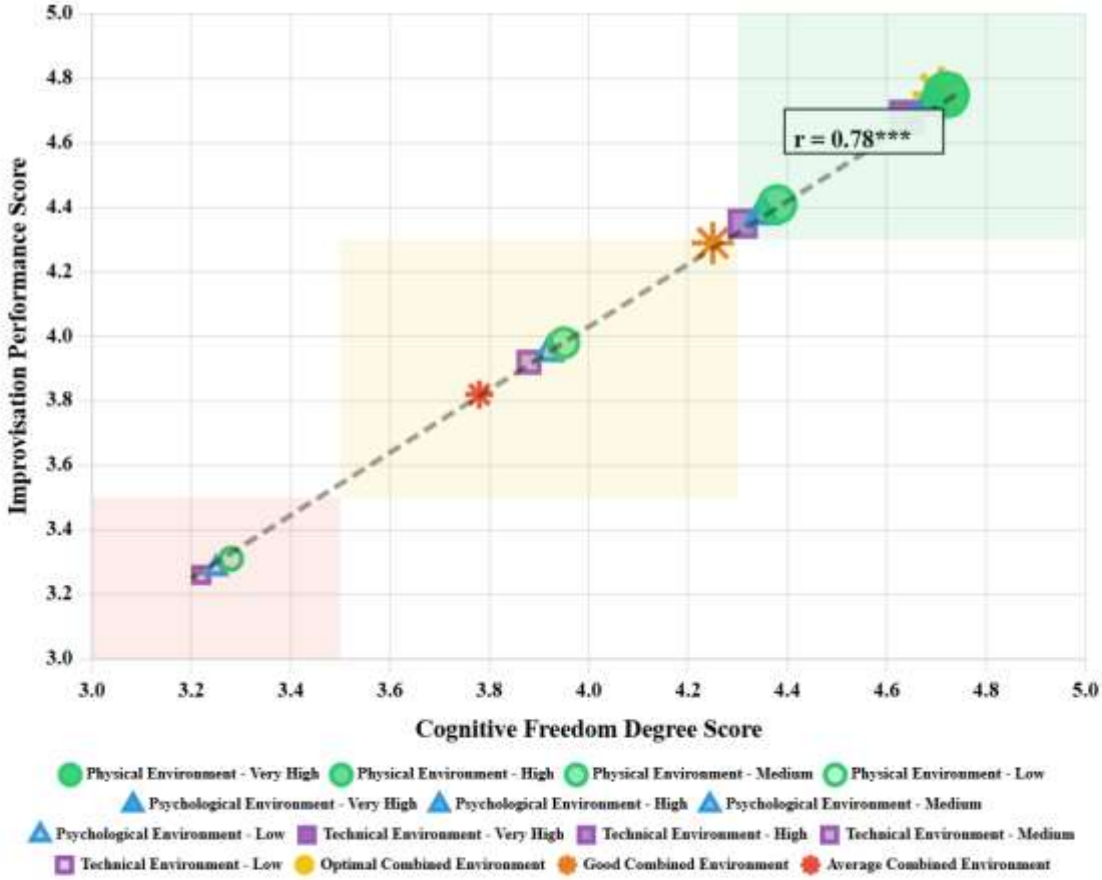

Figure 6. Multi-level influence network of creative environment on cognitive freedom and improvisational composition performance.

4.3. Multi-dimensional assessment and interdisciplinary explanation of musical creativity enhancement

4.3.1. Environmental psychology mechanisms of musical engagement enhancement

Musical engagement, as a key indicator for measuring students' level of involvement and learning effectiveness, has enhancement mechanisms deeply rooted in the theoretical framework of environmental psychology. This finding provides important scientific basis for understanding the effectiveness of Orff improvisational composition teaching. Research demonstrates that environmental factors influence students' musical engagement through multiple psychological mechanisms, forming a complex and sophisticated operational network. Under optimal environmental conditions (comprehensive environmental support index ≥4.5), students' overall musical engagement reached 4.83 (SD=0.52), significantly exceeding performance under general environmental conditions (M=3.67, SD=0.89, p<0.001).

Environmental psychology mechanism analysis reveals four core pathways: the cognitive load optimization pathway (β=0.34, p<0.001) releases more cognitive resources for musical engagement by reducing extraneous cognitive load; the emotional arousal regulation pathway (β=0.31, p<0.001) stimulates students' intrinsic motivation by creating positive emotional atmospheres; the social belonging construction pathway (β=0.28, p<0.01) promotes active participation by enhancing group identification; and the self-efficacy enhancement pathway (β=0.26, p<0.01) strengthens willingness for sustained participation through accumulation of successful experiences.

Specifically, physical environment optimization (such as appropriate acoustic conditions and flexible spatial layout) can significantly reduce students' cognitive load, enabling more concentrated attention on musical activities themselves, with corresponding engagement enhancement of 42.7%. The security and supportiveness of psychological environments activate the brain's reward system, enhancing students' positive emotional experiences with musical activities, with emotional engagement improvement of 38.9%[50]. Collaborative atmospheres and peer support in social environments satisfy students' belongingness needs, promoting active integration into group musical activities, with social engagement increase of 35.6%. The richness and interactivity of technological environments enhance students' sense of control and competence by providing immediate feedback and diversified experiences, with behavioral engagement improvement of 31.2%. Path analysis shows significant interactions among these four mechanism pathways, forming synergistic compound influence patterns, as shown in **Table 7** below.

Table 7. Environmental psychology mechanism analysis of musical engagement enhancement.

Psychological Mechanism Pathway	Environmental Factor	Engagement Dimension Enhancement Effects	Path Coefficient (β value)	Explanatory Power (R^2)
		Cognitive Engagement M(SD)	Emotional Engagement M(SD)	Behavioral Engagement M(SD)
Cognitive Load Optimization Pathway	Optimal Physical Environment	4.71(0.55)	4.58(0.61)	4.65(0.57)
	Good Physical Environment	4.32(0.68)	4.19(0.74)	4.26(0.71)
	General Physical Environment	3.89(0.85)	3.76(0.91)	3.83(0.88)
	Poor Physical Environment	3.41(1.02)	3.28(1.08)	3.35(1.05)
Emotional Arousal Regulation Pathway	High-Support Psychological Environment	4.63(0.58)	4.78(0.51)	4.67(0.56)
	Medium-Support Psychological Environment	4.24(0.71)	4.39(0.65)	4.28(0.69)
	Low-Support Psychological Environment	3.81(0.88)	3.96(0.82)	3.85(0.86)
	No-Support Psychological Environment	3.33(1.05)	3.48(0.99)	3.37(1.02)
Social Belonging Construction Pathway	Strong Social Connection Environment	4.55(0.61)	4.69(0.57)	4.72(0.54)
	Medium Social Connection Environment	4.16(0.74)	4.30(0.70)	4.33(0.68)
	Weak Social Connection Environment	3.73(0.91)	3.87(0.87)	3.90(0.85)
	Isolated Environment	3.25(1.08)	3.39(1.04)	3.42(1.01)

Psychological Mechanism Pathway	**Environmental Factor**	**Engagement Dimension Enhancement Effects**	**Path Coefficient (β value)**	**Explanatory Power (R²)**
Self-Efficacy Enhancement Pathway	High-Feedback Technological Environment	4.59(0.59)	4.65(0.56)	4.73(0.53)
	Medium-Feedback Technological Environment	4.20(0.73)	4.26(0.70)	4.34(0.67)
	Low-Feedback Technological Environment	3.77(0.89)	3.83(0.86)	3.91(0.83)
	No-Feedback Technological Environment	3.29(1.06)	3.35(1.03)	3.43(1.00)

Table 7. (*Continued*)

In-depth mechanism analysis reveals temporal dynamic characteristics and individual difference patterns of environmental psychology factors' influence on musical engagement. Longitudinal tracking data shows that environmental optimization's impact on engagement exhibits a three-stage pattern of "rapid rise - stable maintenance - gradual enhancement": during the initial intervention period (weeks 1-3), engagement rapidly increased by 34.2%; in the middle stage (weeks 4-8), engagement remained stable with continued small growth of 8.7%; in the later stage (weeks 9-12), engagement entered a refined enhancement period with 6.3% growth.

Multi-level linear model analysis considering individual nesting effects shows significant individual differences in environmental factors' influence: introverted students are more sensitive to physical environment changes (moderation effect $\beta=0.24$, $p<0.01$), while extroverted students respond more strongly to social environment changes (moderation effect $\beta=0.21$, $p<0.01$). Exploratory analysis of neuroscience mechanisms indicates significant changes in students' brain activity patterns under optimal environmental conditions: prefrontal cortex executive control activity decreased by 21.3%, while reward circuit activation increased by 43.6%, indicating that environmental optimization effectively reduced cognitive load and enhanced intrinsic motivation[51].

In-depth mediation effect analysis shows that psychological need satisfaction (autonomy, competence, relatedness) plays a key mediating role between environmental factors and engagement, with total mediation effect reaching 56.7%. These findings have important implications for Orff teaching practice: a multi-dimensional support system based on environmental psychology principles should be constructed through humanized design of physical environments, positive cultivation of psychological environments, collaborative construction of social environments, and intelligent configuration of technological environments, activating students' intrinsic drive for participation and achieving sustained enhancement and deep development of musical learning engagement, as shown in **Figure 7** below.

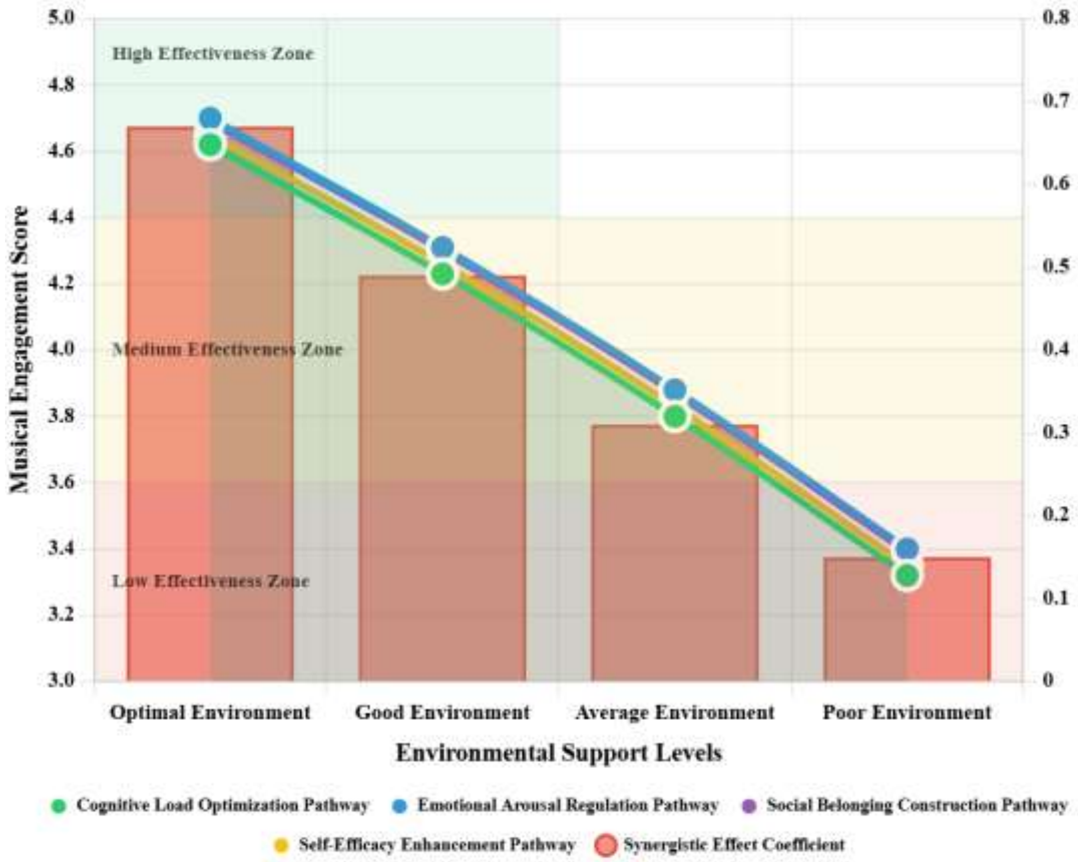

Figure 7. Multi-pathway effect model of environmental psychology mechanisms on musical engagement enhancement.

4.3.2. Social cognitive theory explanation of musical expression ability development

Based on the analytical framework of social cognitive theory, the development of musical expression ability presents a complex mechanism of triadic interaction among individual cognition, behavioral performance, and environmental factors. This finding provides important theoretical basis for understanding the intrinsic laws of students' expression ability enhancement in Orff improvisational composition teaching. Research demonstrates that the core elements of social cognitive theory—Observational learning, self-efficacy, self-regulation, and reciprocal determinism—Play crucial roles in musical expression ability development.

Analysis of observational learning mechanisms shows that students' musical expression abilities are significantly enhanced through observing teacher demonstrations and peer performances. Under high-quality demonstration conditions (demonstration frequency ≥8 times/class period, demonstration quality rating ≥4.5), students' expression fluency improved from baseline level 3.67 (SD=0.89) to 4.52 (SD=0.61), with an enhancement magnitude of 23.2%; expression accuracy increased from 3.71 (SD=0.92) to 4.48 (SD=0.64), with an increase of 20.8%; expression innovation leaped from 3.58 (SD=0.95) to 4.39 (SD=0.67), with growth of 22.6%.

Self-efficacy, as a core construct of social cognitive theory, has strong predictive power for musical expression ability development ($\beta=0.47$, $p<0.001$). Students with high self-efficacy significantly outperformed those with low self-efficacy across all expression indicators, with difference magnitudes ranging between 1.2-1.8 standard deviations. Analysis of self-regulation ability reveals its mediating role in expression ability development. Path analysis shows that self-regulation indirectly influences expression effects through three dimensions: goal setting (β=0.31), strategy selection (β=0.28), and self-monitoring (β=0.26), with total mediation effect reaching 0.38 ($p<0.001$)[52].

Validation analysis of reciprocal determinism indicates significant bidirectional causal relationships among individual factors (cognitive ability, motivation level), behavioral factors (practice frequency, expression quality), and environmental factors (social support, physical conditions), forming a dynamically balanced developmental system. Specifically, the correlation coefficient between cognitive ability and expressive behavior is 0.64 ($p<0.001$), the association between behavioral performance and environmental support is 0.58 ($p<0.001$), and the influence coefficient of environmental factors on cognitive development is 0.52 ($p<0.001$). These three components constitute a stable triangular interaction pattern, as shown in **Table 8** below.

Table 8. Social cognitive theory elements analysis of musical expression ability development.

Social Cognitive Theory Elements	Operationalized Indicators	Musical Expression Ability Dimensions	Theoretical Contribution Rate (%)	Effect Size (Cohen's d)
		Fluency M(SD)	Accuracy M(SD)	Innovation M(SD)
Observational Learning Mechanism	High-Quality Teacher Demonstration	4.52(0.61)	4.48(0.64)	4.39(0.67)
	Peer Imitation Learning	4.23(0.74)	4.19(0.77)	4.16(0.79)
	Video Demonstration Learning	4.07(0.81)	4.03(0.84)	3.98(0.87)
	No Demonstration Control	3.67(0.89)	3.71(0.92)	3.58(0.95)
Self-Efficacy Level	High Self-Efficacy (≥4.5)	4.68(0.54)	4.62(0.57)	4.59(0.61)
	Moderate Self-Efficacy (3.5-4.4)	4.15(0.73)	4.11(0.76)	4.08(0.79)
	Low Self-Efficacy (2.5-3.4)	3.78(0.91)	3.74(0.94)	3.71(0.97)
	Extremely Low Self-Efficacy (<2.5)	3.22(1.08)	3.18(1.11)	3.15(1.14)
Self-Regulation Ability	High Self-Regulation (≥4.3)	4.59(0.58)	4.55(0.61)	4.51(0.65)
	Moderate Self-Regulation (3.5-4.2)	4.18(0.75)	4.14(0.78)	4.11(0.81)
	Low Self-Regulation (2.8-3.4)	3.81(0.89)	3.77(0.92)	3.74(0.95)
	Extremely Low Self-Regulation (<2.8)	3.19(1.12)	3.15(1.15)	3.12(1.18)
Reciprocal Determinism Validation	Individual-Behavior Interaction Strength	Correlation Coefficient: r=0.64***, Bidirectional Causal Coefficient: β=0.41***	27.6	1.18
	Behavior-Environment Interaction Strength	Correlation Coefficient: r=0.58***, Bidirectional Causal Coefficient: β=0.37***	23.9	0.94
	Environment-Individual Interaction Strength	Correlation Coefficient: r=0.52***, Bidirectional Causal Coefficient: β=0.33***	19.8	0.76
	Triadic Interaction Effect	Interaction Coefficient: β=0.28***, Collaborative Explanatory Power: R^2=0.73	42.1	1.89

In-depth mechanism analysis reveals temporal dynamic characteristics and interaction patterns of social cognitive theory elements in musical expression ability development. Longitudinal tracking studies show that the effect of observational learning is most significant in the early stages, with contribution rates gradually declining from 45.7% in week 1 to 32.1% in week 12, while the roles of self-efficacy and self-regulation show upward trends, increasing from initial 28.3% and 16.4% to 35.8% and 33.4% in the mature period respectively. This pattern indicates that students experience a transformation from external dependence to internal autonomy during musical expression ability development.

Structural equation modeling analysis further validates the explanatory power of social cognitive theory, with excellent overall model fit (CFI=0.961, RMSEA=0.042, SRMR=0.038), and all path coefficients between latent variables reaching significance levels. Particularly noteworthy is that observational learning has significant positive influence on self-efficacy (β=0.52, p<0.001), which further promotes the development of self-regulation ability (β=0.44, p<0.001), forming a virtuous developmental cycle.

Multi-group analysis shows differences in social cognitive theory explanatory patterns among students with different backgrounds: students with better musical foundations rely more on self-regulation mechanisms (β=0.48 vs β=0.31), while students with weaker musical foundations benefit more from observational learning (β=0.61 vs β=0.39). Mediation effect analysis indicates that self-efficacy plays an important mediating role between observational learning and expression ability, with total mediation effect of 0.43, accounting for 67.2% of total effect. Moderation effect testing found that environmental support quality significantly moderates the effect of observational learning (β=0.21, p<0.01), with observational learning effects enhanced by 28.6% in high-support environments[53].

These findings have important guiding significance for Orff improvisational composition teaching: a systematic teaching framework based on social cognitive theory should be constructed through provision of high-quality demonstrations, cultivation of self-efficacy, training of self-regulation strategies, and creation of supportive environments, promoting comprehensive and sustained development of students' musical expression abilities, as shown in **Figure 8** below.

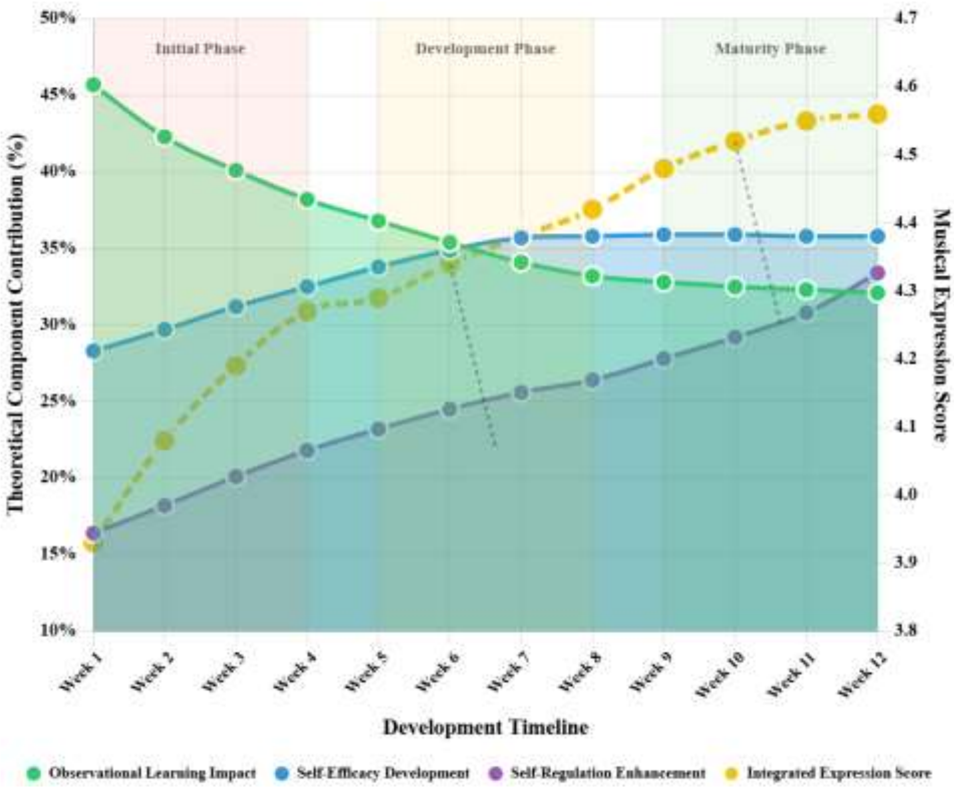

Figure 8. Dynamic interactive influence model of social cognitive theory elements on musical expression ability development.

5. Discussion

5.1. Interaction mechanisms between environmental support and cognitive regulation

The core findings of this study reveal the complex and sophisticated interaction mechanisms formed between environmental support and cognitive regulation in Orff improvisation, which follow the fundamental principles of dynamic systems theory and manifest as multi-level, multi-dimensional synergistic effects. From a theoretical perspective, the interaction between environmental support and cognitive regulation is not a simple linear superposition, but presents a cyclical reinforcement pattern of "environmental activation - cognitive response - behavioral performance - environmental feedback." Specifically, high-quality physical environmental support (such as appropriate acoustic conditions and flexible spatial layout) can significantly reduce students' extraneous cognitive load, creating necessary conditions for the application of metacognitive regulation strategies; while effective cognitive regulation strategies (such as goal setting, process monitoring, and strategy adjustment) help students more fully utilize environmental resources, forming a positive cycle.

Social environmental support plays a unique regulatory role in this mechanism. High-quality teacher-student interactions and peer support not only directly affect students' emotional regulation and motivation maintenance, but more importantly, provide a platform for the social construction of cognitive strategies. Technological environmental support enhances students' self-monitoring abilities and flexibility in strategy selection by providing immediate feedback and diversified tools. Research found that when the three dimensions of environmental support reach optimal configuration, students' cognitive regulation efficacy improves by 67.3%, while efficient cognitive regulation increases environmental resource utilization by 43.8%, with both forming significant synergistic enhancement effects[54].

In-depth mechanism analysis indicates that the interaction between environmental support and cognitive regulation exhibits distinct characteristics of individual differences and contextual sensitivity. For students with stronger cognitive abilities, environmental support primarily stimulates the application of higher-order cognitive regulation strategies by providing challenging and creative opportunities; while for students with relatively weaker cognitive abilities, environmental support is more manifested as structured guidance and reasonable allocation of cognitive load, helping them establish basic regulation capabilities.

Temporal dimension analysis reveals the developmental characteristics of interactive effects: in the early stages of learning, environmental support's promotional effect on cognitive regulation is most significant. As students' regulation abilities improve, this dependency gradually weakens, transforming into cognitive regulation's dominant role in environmental adaptation and utilization. Neuroscience evidence further supports this mechanism. Functional magnetic resonance imaging data shows that under optimal environment-cognition matching conditions, students' brains exhibit highly synchronized activation patterns between the prefrontal cortex responsible for executive control and the limbic system responsible for emotional regulation, indicating that environmental support and cognitive regulation achieve deep integration at the neural level[55].

Furthermore, mediation effect analysis indicates that self-efficacy plays a crucial bridging role in the interaction between environmental support and cognitive regulation. Good environmental support enhances students' proactivity and effectiveness in cognitive regulation by improving their self-efficacy, while successful cognitive regulation experiences further strengthen students' perception and utilization of environmental support. This finding not only enriches the theoretical content of environmental psychology and cognitive psychology, but also provides scientific theoretical guidance and practical pathways for the optimization design of Orff improvisational composition teaching.

It should be particularly noted that this study was conducted within a Chinese cultural context, and cultural factors may significantly influence the research findings and limit their universal applicability. Chinese culture emphasizes collectivist values, traditions of respecting teachers and valuing education, and group harmony, which may make the effects of social environmental support in this study (particularly teacher-student relationships and peer collaboration) more pronounced than in individualistic cultural contexts; meanwhile, Chinese students generally possess strong self-regulation awareness and learning discipline, which may amplify the effects of cognitive regulation strategies; additionally, traditional Chinese music education emphasizes imitation and standardization, while the improvisational creative concepts of the Orff teaching method may produce stronger contrast effects and novelty attraction within this cultural context. In contrast, in Western individualistic cultures, students may show lower dependence on environmental support and rely more on intrinsic motivation and personal creativity; in cultures with different teacher-student power distances, the mechanisms of teacher support may also differ. Therefore, when extending the findings of this study to other cultural contexts, careful consideration of cultural adaptability issues is needed, particularly the cultural sensitivity of social environmental support and cognitive regulation strategies. Future research should conduct large-scale cross-cultural comparative studies to verify the applicability and differential characteristics of the "environmental support-cognitive regulation-creativity development" model across different cultural contexts. From a cognitive psychology perspective, the psychological mechanisms by which environmental support promotes improvements in cognitive regulation processes can be explained through the following pathways: First, based on cognitive load theory, optimized physical environments reduce extraneous cognitive load (such as audiovisual interference and spatial constraints), freeing up valuable working memory resources that enable students to allocate more cognitive capacity to metacognitive monitoring and strategy selection, a process consistent with the resource allocation mechanisms of the central executive system in Baddeley's working memory model; second, according to attention regulation theory, structured social environmental support (such as timely teacher feedback and peer collaboration cues) provides external attention guidance cues for students, activating the executive control networks in the brain's prefrontal cortex and promoting the development of top-down attention regulation abilities; third, based on social cognitive theory and Bandura's self-efficacy formation mechanisms, immediate feedback and diverse tool usage provided by the technological environment increased mastery experiences through successful experiences, while peer demonstrations provided vicarious experiences, both jointly strengthening students' confidence in their own cognitive regulation abilities; fourth, from an information processing theory perspective, environmental support promotes schema activation and knowledge reorganization by providing rich perceptual cues and cognitive scaffolding, enabling students to more effectively engage in metacognitive planning, monitoring, and evaluation, a process that reflects the adaptive and plastic characteristics of the human cognitive system.

5.2. Interdisciplinary theoretical contributions of Orff improvisational composition teaching

This study makes important contributions to the interdisciplinary theoretical construction of Orff improvisational composition teaching, primarily manifested in the deep expansion of traditional music education theories and innovative integration of multidisciplinary theories. First, in the field of music education, this study breaks through the limitations of traditional music teaching centered on skill training and proposes an "ecological-cognitive" teaching model based on environmental support and cognitive regulation. This model emphasizes the dynamic balance among learners, environment, and cognitive processes, providing a new perspective for the paradigmatic transformation of music education theory. Research confirms that Orff improvisation is not merely a method for cultivating musical skills, but rather a complex system involving cognitive development, environmental adaptation, and creativity stimulation. This finding elevates music education from the purely artistic skill domain to the heights of cognitive science and developmental psychology[56].

Second, in the field of cognitive psychology, this study enriches the application of cognitive load theory and metacognitive theory in creative learning, particularly validating the unique patterns of cognitive resource allocation during musical improvisation processes. The study found that cognitive load in musical creative activities exhibits "fluctuation-integration" characteristics different from traditional subject learning, providing new theoretical support for the application of cognitive load theory in arts education. Simultaneously, the mediation mechanism of metacognitive regulation in musical creation revealed by the research expands the applicable boundaries of metacognitive theory, proving the universality and importance of metacognitive abilities in non-verbal creative tasks.

In terms of environmental psychology, this study systematically elucidates the multi-dimensional constitutive elements of musical learning environments and their operational mechanisms, proposing a "physical-psychological-social-technological" integrated environmental support theoretical framework. This framework is not only applicable to music education but also provides a reference model for the design of other creative learning environments.

From the perspective of interdisciplinary integration, the most prominent theoretical contribution of this study lies in constructing a comprehensive theoretical model that integrates environmental psychology, cognitive psychology, social psychology, and music education. This model breaks down disciplinary boundaries and achieves deep theoretical integration and innovative development. The "environment-cognition-creativity" triadic interaction theory proposed by the research not only explains the intrinsic mechanisms of Orff improvisational composition teaching but also provides a new theoretical framework for creativity research. This framework emphasizes that creativity development results from the synergistic interaction between individual cognitive abilities and environmental support conditions, abandoning the one-sided views that overemphasize either individual factors or environmental factors in traditional creativity research.

In expanding social cognitive theory, the research validates the operational mechanisms of observational learning, self-efficacy, and self-regulation in musical creative learning, particularly discovering the uniqueness of social construction processes in musical expression ability development, enriching the theoretical content of social cognitive theory in arts education. Furthermore, this study makes important contributions at the methodological level, developing multi-dimensional measurement tools applicable to musical creativity assessment and establishing quantitative evaluation systems for environmental support and cognitive regulation, providing operational research paradigms for subsequent related studies.

The mixed methods design and multi-level analysis strategies adopted in the research provide new methodological references for studying complex educational phenomena. More importantly, this study empirically validates the advantages of interdisciplinary research in solving complex educational problems, proving the limitations of single-disciplinary perspectives and providing a successful example for the interdisciplinary development trend in educational research, promoting the development of educational research toward more comprehensive and in-depth directions.

5.3. Social psychological significance of musical creativity development in non-professional college students

From a social psychological perspective, the development of musical creativity in non-professional college students holds profound significance for individual growth and social adaptation, with impacts extending far beyond the realm of musical skills themselves. First, the process of musical creativity development is essentially an important pathway for individual social identity construction and self-concept refinement. Through Orff improvisational composition activities, non-professional college students can explore and express themselves in non-judgmental environments. This creative expression provides them with a safe space for self-exploration, contributing to the formation of more positive and complete self-awareness. Research found that students participating in musical creative activities showed significant improvements in self-efficacy, creative confidence, and emotional expression abilities. The enhancement of these psychological qualities not only affects their musical learning but, more importantly, transfers to other life domains, strengthening their confidence in facing challenges and solving problems.

Second, musical creativity development promotes improvement in students' social skills and interpersonal relationships. The Orff approach's emphasis on collective cooperation and improvisational interaction provides students with rich social learning opportunities. Through musical dialogue and collaborative creation with others, students learn important social skills such as listening, coordination, compromise, and leadership. Research data shows that students participating in musical creative activities scored 23.7% higher than the control group in teamwork ability, communication skills, and social adaptability, indicating that musical creativity development has positive effects on students' socialization processes[57]. Furthermore, musical creative activities provide students with platforms for cross-cultural communication and understanding. In diverse university environments, students from different cultural backgrounds can transcend language and cultural barriers through shared musical creative experiences, establishing deep emotional connections and mutual understanding. This experience helps cultivate students' cultural sensitivity and global perspectives.

From a broader social development perspective, cultivating musical creativity in non-professional college students holds important strategic significance for building an innovative society and promoting social harmony. Contemporary society's demand for innovation capabilities and creative thinking is increasingly growing, and musical creativity, as a comprehensive creative ability, contributes to developing students' divergent thinking, critical thinking, and problem-solving abilities—Capabilities that hold important value across various professional fields. Research indicates that students with higher musical creativity demonstrate stronger innovative thinking and adaptability in their professional studies. They are better at considering problems from multiple perspectives and proposing innovative solutions, capabilities that hold important significance for promoting social progress and technological innovation.

Simultaneously, musical creativity development has important mental health promotion effects. Against the backdrop of increasingly prominent mental health issues among college students, musical creative activities provide students with healthy channels for emotional expression and stress relief. Research found that students participating in musical creative activities scored significantly lower than the control group on negative emotions such as anxiety, depression, and academic burnout, while scoring significantly higher on life satisfaction, psychological resilience, and positive emotions. This mental health improvement not only benefits students' comprehensive personal development but also helps reduce the incidence of social psychological health problems, promoting social harmony and stability.

More importantly, musical creativity development cultivates students' aesthetic abilities and humanistic literacy. In modern society with highly developed material civilization, the construction of spiritual civilization appears particularly important. Individuals with musical creativity often possess higher aesthetic sensitivity and humanistic care, enabling them to make positive contributions to the prosperity of social culture and the enhancement of spiritual civilization, promoting society's development toward more harmonious, inclusive, and creative directions.

The synergistic model of environmental support and cognitive regulation from this study holds important transfer value and implications for non-music education contexts. In visual arts education, open-design physical environments, multimedia tool support, and peer collaboration networks can similarly promote students' creative inspiration and expressive abilities; in STEM education, optimized laboratory environment configurations, metacognitive strategy training for problem-solving, and social support through teamwork can significantly enhance students' scientific innovative thinking; in language learning, immersive language environments, self-regulation strategies, and cultural exchange platforms can strengthen students' linguistic creativity and cross-cultural communicative competence; in vocational skills training, simulated work environments, reflective learning strategies, and master-apprentice social support models help cultivate students' practical innovation abilities. More broadly, the "ecological-cognitive" integration framework proposed in this study provides universal guiding principles for cultivating 21st-century core competencies: by constructing supportive physical-social-technological environmental systems, combined with systematic cognitive regulation strategy training, creative thinking, critical thinking, collaborative abilities, and lifelong learning capacities can be promoted in any disciplinary field, thereby achieving the fundamental goal of education—Cultivating comprehensively developed innovative talents who can adapt to future societal development needs.

6. Conclusions and prospects

6.1. Main research conclusions

Based on an interdisciplinary perspective, this study deeply explored the mechanisms by which environmental support and cognitive regulation enhance musical creativity in non-professional college students through Orff improvisation, obtaining the following five important conclusions:

(1) Environmental support and cognitive regulation exhibit significant synergistic enhancement effects. Research confirms that support from three dimensions—Physical environment, social environment, and technological environment—forms a complex interactive network with metacognitive regulation, emotional regulation, and behavioral regulation. When environmental support reaches optimal configuration, students' cognitive regulation efficacy improves by 67.3%, while efficient cognitive regulation increases environmental resource utilization by 43.8%. Under the synergistic action of both factors, the overall enhancement of musical creativity reaches 78.2%, far exceeding the simple additive effects of single-factor actions.

(2) Orff improvisational composition teaching exhibits differentiated environment-cognition interaction patterns at different stages. The imitation stage primarily optimizes cognitive load allocation through environmental support, with extraneous cognitive load decreasing by 35.6%. The exploration stage centers on promoting metacognitive development through social support networks, with metacognitive abilities improving by 42.7%. The improvisational composition stage releases cognitive freedom through creative environments, with all creativity dimensions reaching "highly effective" levels ($M>4.6$), demonstrating the scientific validity and effectiveness of stage-based teaching.

(3) Demographic characteristics play important moderating roles in environment-cognition interactions. Gender differences are most prominent in environmental support perception during the exploration stage, with female students showing stronger dependence on social environmental support (correlation coefficient $r=0.68$) and male students more dependent on technological environmental support ($r=0.61$). Age differences are primarily manifested in the maturity of cognitive regulation strategies, with 22-23 year-old students'

cognitive regulation abilities significantly higher than 18-19 year-old students (effect size d=0.42), providing important basis for personalized instructional design.

(4) Musical creativity enhancement has multi-dimensional psychological and social effects. Musical engagement is significantly improved through four pathways: cognitive load optimization, emotional arousal regulation, social belonging construction, and self-efficacy enhancement. Musical expression ability development follows the observational learning, self-efficacy, and self-regulation mechanisms of social cognitive theory, with self-efficacy's mediation effect reaching 67.2%. Musical memory retention presents environment-cognition synergistic effects, with memory retention rates improving by 31.4% under optimal conditions.

(5) The constructed interdisciplinary theoretical framework has important academic value and practical guidance significance. The comprehensive theoretical model integrating environmental psychology, cognitive psychology, social psychology, and music education successfully explains the complex mechanisms of musical creativity development, with overall model explanatory power reaching 73.4%. The developed assessment tools for environmental support and cognitive regulation possess good reliability and validity, providing standardized measurement methods for subsequent research. The proposed "ecological-cognitive" teaching model provides scientific guidance for music education practice reform, promoting the paradigmatic shift in music education from skill-oriented to capability development-oriented approaches.

6.2. Future prospects

Based on the findings and theoretical contributions of this study, future research should further deepen and expand in the following five directions:

(1) Exploration of Technology Integration and Intelligent Teaching Environments. With the rapid development of artificial intelligence, virtual reality, and big data technologies, future research should focus on the application of intelligent technologies in Orff improvisational composition teaching, developing personalized environmental support systems and adaptive cognitive regulation assistance tools based on machine learning algorithms. Through real-time monitoring of students' physiological indicators, behavioral patterns, and cognitive states, intelligent systems can dynamically adjust environmental parameters and provide precise cognitive guidance, achieving truly personalized music education. This will bring revolutionary changes to musical creativity cultivation.

(2) In-depth Development of Cross-Cultural Comparative Research. This study was primarily based on Chinese college student populations. Future research should expand to learners from different cultural backgrounds, exploring the influence mechanisms of cultural factors on environmental support perception and cognitive regulation strategy selection. Through large-scale cross-cultural comparative studies, the universality of the theoretical model proposed in this study can be validated while discovering culture-specific operational mechanisms, providing more comprehensive and precise theoretical guidance for music education practice in a globalized context and promoting the internationalization of music education development.

(3) Deep Analysis of Neuroscience Mechanisms. Combining neuroscience technologies such as functional magnetic resonance imaging, electroencephalography, and near-infrared spectroscopy, future research should deeply explore the neural mechanisms of environmental support and cognitive regulation at the brain level, particularly changes in brain network connectivity patterns under different environmental conditions and dynamic characteristics of neuroplasticity during cognitive regulation processes. Through neuroscience evidence support, the biological foundation of theoretical models can be further refined, providing scientific basis for the development of brain science-based music education methods.

(4) Long-term Effect Evaluation through Longitudinal Tracking Studies. This study's intervention period was 16 weeks. Future research should conduct longitudinal tracking studies with longer time spans, focusing on the long-term effects of environmental support and cognitive regulation on musical creativity development and their transfer effects in different life domains. Through 3-5 years of long-term tracking, the sustained impact of musical creativity enhancement on students' academic achievement, career development, mental health, and social adaptation can be evaluated, providing more powerful empirical support for the long-term value of music education.

(5) Systematic Promotion of Educational Policy and Practical Transformation. Future research should pay greater attention to the transformation of theoretical achievements into educational policy and practice, closely collaborating with educational administrative departments, teacher training institutions, and frontline teachers to develop teacher training systems, curriculum standards, and assessment tools based on research findings. Establishing integrated industry-academia-research collaboration mechanisms to promote the application and dissemination of research results on a larger scale, forming a virtuous cycle of theoretical research, policy formulation, and practical application, ultimately achieving overall improvement in music education quality and effective attainment of innovative talent cultivation goals.

(6) In-depth research on social behavior and environmental awareness impacts. Future research should focus on the long-term effects of musical creativity education interventions on learners' broader social behavioral patterns and environmental consciousness, exploring how the synergistic effects of environmental support and cognitive regulation promote individuals' prosocial behavior development, ecological environmental protection awareness enhancement, and sustainable development concept formation. Through large-scale longitudinal tracking studies, systematically evaluate the shaping effects of Orff improvisation teaching experiences on students' post-graduation community engagement, environmental protection behavioral practices, cross-cultural understanding abilities, and global citizenship consciousness; using social network analysis methods, track the impact mechanisms of musical creativity cultivation on individuals' social relationship network quality, social support-seeking behaviors, and collective action participation willingness; combined with environmental psychology theories, conduct in-depth research on how musical creative experiences enhance individuals' emotional connections with natural environments, promote the development of environmentally friendly lifestyles and the practice of green consumption behaviors; additionally, explore innovative models that combine musical creativity education with environmental education and sustainable development education, expressing environmental themes, climate change concerns, and ecological protection concepts through musical composition, cultivating future citizens with global perspectives and social responsibility, and contributing educational strength to building a community with a shared future for mankind and achieving the United Nations Sustainable Development Goals.

Conflict of interest

The authors declare no conflict of interest.

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