Research on Structural Evolution Mechanisms and Inheritance Efficiency of Ethnic Traditional Sports Skills in the Digital Context

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ABSTRACT Digitalization is reshaping the inheritance of ethnic traditional sports skills and craftsmanship by promoting action datafication, spatial virtualization, and subject networking. By analyzing the shared physicality, ritualism, and symbolism of traditional skills, this study reveals their structural evolution mechanisms in the digital context. A four-dimensional inheritance efficiency model incorporating speed, precision, breadth, and fidelity is constructed, and AHP weighting is combined with deep learning evaluation algorithms. Comparative analysis of martial arts, wrestling, and archery shows that digitalization reduces learning cycles by 27.6% and expands the transmission radius by 18.6 times, while cultural fidelity decreases by 23.7%. The paradox between technical efficiency and cultural loss reflects the tension between technological rationality and cultural logic. Accordingly, a core–periphery dual-track strategy is proposed to seek a dynamic balance between technological empowerment and cultural preservation. The study provides methodological references for motion capture, digital encoding, and wireless sensing-based transmission of embodied skills in engineering and intelligent monitoring scenarios.

INDEX TERMS ethnic traditional sports skills, structural evolution, inheritance efficiency, wireless sensing, digital encoding

I. INTRODUCTION

ETHNIC traditional sports skills and techniques carry profound cultural memory and embodied production wisdom. However, they face severe challenges in the modernization process, including the loss of inheritors and fragmentation of cultural ecosystems. The widespread application of digital technology opens new pathways to breaking through difficulties, with tools such as virtual reality, motion capture, and cloud platforms reconstructing the recording, display, and dissemination methods of skills [1]. However, technological intervention is not merely a change in technical means but also triggers profound evolution in the ontological structure of skills, inheritance relationship networks, and cultural value systems [2]. Digitalization may also lead to the instrumental reduction of skills. When bodily practice is simplified into data parameters and cultural rituals are compressed into visual symbols, the vitality of these skills may gradually be lost in the process of quantification. Existing research mostly focuses on specific practices of digital applications, lacking systematic explanation of the internal mechanisms of structural evolution, and a scientific measurement system for inheritance efficiency has not yet been established [3,4]. Based on the intersectional perspective of technology social construction theory and cultural adaptation theory, this study analyzes the evolutionary dynamics of skill structures in ethnic sports and production within the digital context, constructing a multi-dimensional inheritance efficiency evaluation model to balance technological empowerment and cultural preservation for the living inheritance of these traditional skills.

II. STRUCTURAL CHARACTERISTICS OF ETHNIC TRADITIONAL SPORTS SKILLS AND DIGITAL ENCODING ANALYSIS

A. THREE-DIMENSIONAL CONSTITUENT ELEMENTS OF SKILL STRUCTURE

As complex cultural syntheses, ethnic traditional sports skills present three-dimensionally interwoven characteristics of physicality, ritualism, and symbolism. The physicality dimension is characterized by refined organization of action systems, including rhythmic control of force application, trajectory design of spatial displacement, and rhythmic coordination of breathing regulation. These elements form coupling mechanisms of muscle memory and neural reflexes

through long-term bodily practice. From the perspective of embodied cognition theory, this bodily knowledge is not simple muscular conditioned reflexes, but embodied wisdom integrating cultural cognitive schemas—the Tai Chi practitioner's comprehension of jin (internal force), the Mongolian wrestler's grasp of force points are essentially crystallizations of long-term interaction among body, mind, and cultural environment. The ritualism dimension manifests as proceduralized rules of skill performance, encompassing sequential norms of equipment preparation, directional considerations of venue arrangement, and ceremonial discourse of opening and closing, constructing sacred spatiotemporal boundaries distinct from daily bodily activities. The symbolism dimension, through cultural symbolic systems such as costume patterns, equipment shapes, and action naming, carries the function of intergenerational transmission of ethnic historical narratives and value concepts, collectively constituting the essential attributes distinguishing traditional skills from modern competitive sports [5].

B. DECONSTRUCTION PATHWAYS OF DIGITAL TECHNOLOGY ON SKILL STRUCTURE

Digital technology's intervention in traditional skill inheritance fields implements structural deconstruction through three mechanisms: encoding conversion, medium replacement, and relationship reorganization. The encoding conversion mechanism transforms tacit bodily knowledge into visualized data. Motion capture systems record joint trajectories at 120 fps, generating coordinate matrices with angle, velocity, and acceleration parameters. This process converts skills traditionally acquired through imitation into precise digital representations. However, this process follows a reductive logic: holistic bodily experience is decomposed into measurable parameters. When martial arts' qi-yun (vital energy) becomes respiratory frequency curves, and archery's unity with nature is quantified as muscle activation sequences, cultural meaning systems risk dilution. The medium replacement mechanism breaks the dependence of skill inheritance on specific spatiotemporal scenes. Virtual reality technology constructs immersive training environments where learners can practice actions without being in actual venues, and traditional skills' attachment relationships to natural environments and seasonal climates are replaced by digitalized scenes. The relationship reorganization mechanism changes the interaction modes of inheritance subjects. Online platforms support one-to-many and many-to-many networked dissemination, breaking through the single-line transmission limitations of the master-apprentice system, causing skill structure to shift from organic wholes to modularized components [6].

C. ENCODING CONVERSION AND DATA MAPPING MECHANISMS OF STRUCTURAL ELEMENTS

The digital encoding of skill elements follows the conversion logic of decomposition–abstraction–reconstruction, establishing mapping relationships from bodily experience to data symbols. Encoding of physicality elements adopts biomechanical models of movement, decomposing complex actions into basic movement units. Each unit contains three elements: initial posture, movement trajectory, and terminal posture. Inertial measurement units collect muscle activation sequences and joint torque changes, forming basic entries of the action database (see Figure 1). Encoding of ritualism elements employs contextual semantic annotation technology, providing structured descriptions of the spatiotemporal organization, procedural sequences, and discourse systems of traditional rituals. Ontology modeling methods construct ritual knowledge graphs to achieve computer-readable expression of ritual processes. Encoding of symbolism elements utilizes image recognition and natural language processing algorithms to extract visual feature vectors of costume patterns and equipment shapes, establishing mapping matrices between symbolic forms and cultural connotations. However, this mapping essentially forces a binding between signifier and signified, ignoring the contextual dependence and interpretive diversity of symbolic meanings. The encoding conversion process inevitably produces information loss, as digital representations struggle to fully reproduce the textural dimension of bodily perception, the emotional dimension of ritual experience, and the collective dimension of symbolic identification [7].

III. EVOLUTIONARY DYNAMIC MECHANISMS OF SKILL STRUCTURE IN THE DIGITAL FIELD

A. STRUCTURAL REORGANIZATION PATTERNS TRIGGERED BY TECHNOLOGICAL EMBEDDING

Digital technology's embedding in traditional skill fields triggers recombination of structural elements, presenting evolutionary patterns of decoupling–reconstruction–emergence. From a systems theory perspective, this process is essentially a phase transition of the skill system from high coupling-low modularity to low coupling-high modularity. The decoupling stage manifests as separation of tightly bound elements in the original structure: action practice can be conducted separately from ritual contexts, cultural symbols can be disseminated independently of bodily practice, and the wholeness of skills is decomposed into independently operable functional modules. The reconstruction stage embodies new combinations of elements in digital environments: virtual reality systems combine action training modules with gamification incentive mechanisms, online communities integrate skill display with social interaction functions, forming hybrid structures distinct from traditional forms [8]. The emergence stage produces new attributes not present in traditional structures: data analysis functions enable quantitative tracking of individual learning progress, algorithm recommendation mechanisms customize learning paths based on user preferences, and artificial intelligence assistance systems provide real-time action correction feedback. This algorithm-mediated learning fundamentally changes the cognitive mode of skill inheritance—learners no longer rely on masters' oral instruction and

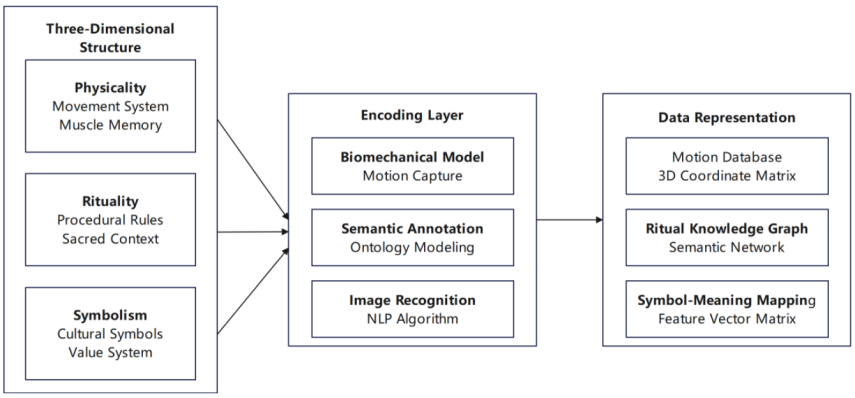

FIGURE 1. Framework of Digital Encoding Conversion for Skill Structural Elements

their own repeated exploration, but calibrate actions through continuous dialogue with algorithms, causing subtle shifts in learning subjectivity. Structural reorganization follows a function priority principle. Digital tools tend to strengthen quantifiable and replicable physical elements, resulting in a functional shift in skill structures [9].

B. NETWORKED RECONSTRUCTION OF INHERITANCE SUBJECT RELATIONSHIPS

Digital platforms break the hierarchical structure of traditional master-apprentice systems, constructing decentralized inheritance network topologies. In traditional modes, knowledge is unidirectionally transmitted from master to apprentice, with inheritance relationships presenting tree-branch structures where masters hold interpretive authority over knowledge and control over inheritance progress [10]. In digitalized scenarios, online platforms support learners' direct access to skill databases, autonomous learning through diverse resources such as video tutorials and three-dimensional models. Knowledge sources expand from single masters to distributed nodes, and inheritance networks evolve from tree structures to network structures. However, this decentralization also brings concerns of authority vacuum—when everyone can become a knowledge publisher, who ensures the accuracy of knowledge and cultural orthodoxy? In traditional master-apprentice systems, masters are not only technical instructors but also cultural interpreters and value guardians; this cultural authority is diluted or even dissolved in networked inheritance.

Subject roles undergo functional reorganization: traditional inheritors differentiate into multiple roles of content producers, platform operators, and technology developers; learners transform from passive recipients to active participants, participating in knowledge reproduction through bullet comments, work sharing, and other means. This networked reconstruction improves inheritance efficiency while bringing quality control risks. The lack of authoritative certification mechanisms leads to rapid spread of erroneous knowledge, and fragmented learning weakens systematic understanding, necessitating establishment of new quality assurance mechanisms and achieving trustworthy authentication of inheritance genealogies through blockchain technology [11].

C. ADAPTIVE EVOLUTION IN CULTURAL FIELD TRANSFORMATION

Skills migrate from regionally embedded cultural fields to globally circulating digital spaces, triggering adaptive evolution to respond to environmental changes (see Table 1). In regional fields, skills are deeply integrated with specific natural environments, social customs, and belief systems, with performance timing, participation rules, and aesthetic standards regulated by local culture. Digital spaces present decontextualization characteristics, with skill content stripped from original cultural contexts and made available to global users in standardized formats, facing homogenization pressure on cultural diversity. This field transformation enables skills to reach global audiences but weakens their local cultural moorings.

Empirically, this manifests as a trade-off: while digital platforms expand coverage breadth by 18.6-fold (Table 2), they simultaneously reduce cultural fidelity by 23.7%. This inverse relationship reflects a deeper tension between technical efficiency and cultural integrity—digital tools excel at transmitting quantifiable elements (movements, procedures) but struggle to convey the interpretive frameworks and embodied sensibilities that constitute authentic cultural understanding. Adaptive evolution manifests in three strategies: essentialization strategy strengthens core cultural symbols of skills, maintaining cultural recognizability in digital dissemination by highlighting visual-auditory elements such as ethnic costumes and traditional music; hybridization strategy absorbs popular culture elements for innovative integration, combining traditional martial arts movements with street dance and parkour to create new forms conforming to contemporary aesthetics; stratification strategy provides differentiated content for different audiences, preserving complete ritual versions for cultural insiders. Evolutionary direction is influenced by digital platform algorithm logic; recommendation algorithms on short-video platform favor visually impactful and fast-paced content, prompting skill performances to adapt toward entertainment and fragmenta-

tion [12].

IV. CONSTRUCTION OF MEASUREMENT MODEL FOR SKILL INHERITANCE EFFICIENCY AND EMPIRICAL TESTING

A. CONSTRUCTION OF INDICATOR SYSTEM FOR INHERITANCE EFFICIENCY MEASUREMENT

1) Theoretical Analysis and Operational Definition of Efficiency Dimensions

Inheritance efficiency, as a core indicator measuring the effectiveness of intergenerational skill transmission, requires theoretical deconstruction from a multi-dimensional perspective. Efficiency is decomposed into four theoretical dimensions: the inheritance speed dimension refers to the degree of skill element acquisition per unit time, operationalized as learning cycle (T) and number of mastery stages (S), with calculation formula: speed index $V = S/T$. The inheritance precision dimension refers to the degree of conformity between acquired skills and original skills, quantified through action restoration rate (A) and essential point mastery rate (M), with precision index $P = (A+M)/2$. The inheritance coverage breadth dimension reflects the spatial scope and audience scale of skill dissemination, including number of inheritors (N) and regional distribution density (D), with breadth index $C = N \times D$. The cultural fidelity dimension measures the degree of complete preservation of cultural connotations carried by skills, encompassing ritual context reproduction rate (R) and cultural cognitive depth (K), with fidelity index $F = (R + K)/2$. It should be noted that these four dimensions are not in a simple additive relationship but exhibit internal tensions—speed and fidelity often show negative correlation, and expansion of coverage breadth may come at the cost of precision sacrifice. This tension reflects the deep contradiction between efficiency logic and cultural logic in skill inheritance.

2) Weight Allocation Model Based on Analytic Hierarchy Process

An Analytic Hierarchy Process (AHP) model is constructed to achieve scientific weighting. A three-level hierarchical structure is established: the target layer is comprehensive evaluation value E of inheritance efficiency, the criterion layer consists of four theoretical dimensions, and the indicator layer comprises 16 basic measurement indicators. A review group of 30 experts is invited to conduct pairwise comparisons using a 1–9 scale to form judgment matrices. Calculated criterion layer weight vector: inheritance precision w_1 = 0.35, cultural fidelity w_2 = 0.30, inheritance speed w_3 = 0.20, coverage breadth w_4 = 0.15. Consistency test result CR = 0.078 < 0.1, indicating the judgment matrix is reasonable. The comprehensive evaluation model for inheritance efficiency is:

$$\begin{aligned} E &= w^1 P + w^2 F + w^3 V + w^4 C \\ &= 0.35P + 0.30F + 0.20V + 0.15C \end{aligned} \tag{1}$$

This weight allocation reveals the value orientation of the expert group: quality dimensions (precision + fidelity = 65%) significantly exceed quantity dimensions (speed + breadth = 35%). This structure aligns with the intangible cultural heritage protection concept of "seeing people, seeing objects, seeing life", but it requires vigilance against potential distortion caused by utilitarian dissemination logic in practice. When digital platforms assess inheritance effectiveness using quantitative indicators such as traffic and conversion rates, the weight system may be distorted by practical incentives.

3) Intelligent Evaluation Algorithm Design for Cultural Fidelity

A multi-modal evaluation algorithm based on deep learning is developed to achieve precise measurement of cultural fidelity (see Figure 2). A three-layer neural network architecture is constructed: the first layer is an action semantic recognition module, using 3D convolutional neural networks to extract spatiotemporal features from skill action videos. Input is a $T \times H \times W \times C$ dimensional tensor, which after 5 convolutional-pooling layers outputs a 512-dimensional feature vector. The cosine similarity between the input action sequence and the original skill action library yields the action fidelity A_s. The second layer is a cultural symbol recognition module, adopting BERT pre-trained models to analyze oral content, extract cultural keywords and semantically match with traditional literature libraries, calculating cultural narrative completeness K_s. The third layer is a context restoration degree evaluation module, utilizing Mask R-CNN to identify cultural symbolic elements such as utensils and costumes in scenes, calculating conformity with traditional contexts R_s. The three modules' outputs are integrated through weighted fusion to form comprehensive fidelity:

$$F_{AI} = 0.4A_s + 0.35K_s + 0.25R_s \tag{2}$$

The algorithm achieves 87.3% accuracy in recognizing formal elements (costumes, equipment, ritual sequences) on 500 test samples, with Pearson correlation coefficient r = 0.891 ($p < 0.001$) with manual expert scores on these observable dimensions. However, this validation is limited to surface-level conformity. The algorithm cannot assess the embodied dimensions that experts intuitively evaluate—the learner's internalization of qi-yun (vital energy) or authentic grasp of cultural meanings. Thus, while the algorithm reliably identifies whether ritual procedures are followed correctly, it cannot determine whether learners truly comprehend the cultural logic behind these procedures. This reveals a fundamental limitation: algorithmic assessment conflates formal accuracy with cultural authenticity and cannot penetrate what Michael Polanyi termed tacit knowledge—the deeply embodied understanding that constitutes genuine cultural transmission.

TABLE 1. Comparison of Skill Inheritance Elements in Traditional and Digital Fields

Comparison Dimension	Traditional Cultural Field	Digital Field	Evolution Characteristics
Inheritance Space	Regional embedding (villages, temple fairs)	Virtual extension (platforms, cloud)	De-regionalization
Subject Relationships	Tree hierarchy (master-apprentice)	Network distribution (many-to-many)	Decentralization
Knowledge Form	Tacit experience (bodily memory)	Explicit data (digital models)	Codifiability
Dissemination Logic	Closed transmission (within families)	Open circulation (global access)	Boundary dissolution
Cultural Context	Ritual wholeness (complete context)	Modular segmentation (functional separation)	Fragmentation

Data source: Based on field surveys and digital platform analysis of 15 typical ethnic sports projects (2023–2024)

TABLE 2. Comparison of Four-Dimensional Indicators of Inheritance Efficiency for Three Skill Types

Skill Type	Group	Inheritance Speed V	Inheritance Precision P	Coverage Breadth C	Cultural Fidelity F	Comprehensive Efficiency E
Martial Arts (Tai Chi/Baguazhang)	Experimental	1.43	82.3	29.1	64.2	68.7
Martial Arts (Tai Chi/Baguazhang)	Control	1.03	85.7	1.57	78.6	72.4
Wrestling (Bokh)	Experimental	1.31	79.6	24.8	61.5	66.2
Wrestling (Bokh)	Control	0.97	83.2	1.42	76.3	70.8
Archery	Experimental	1.25	77.4	22.3	58.7	63.5
Archery	Control	0.89	81.5	1.38	82.1	73.6

Data source: 6-month tracking assessment of 180 learners (2022.01–2024.06).

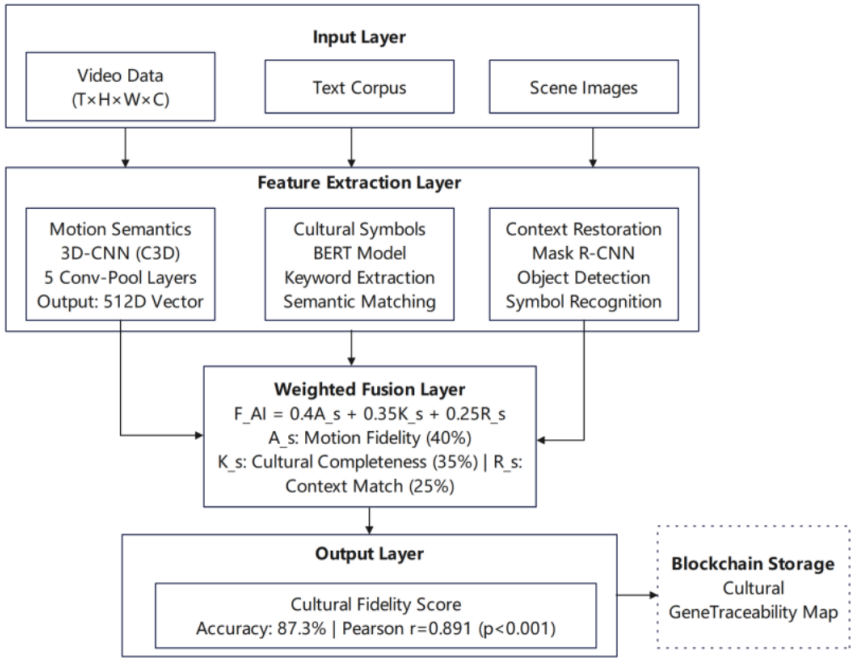

FIGURE 2. Architecture of Intelligent Evaluation Algorithm for Cultural Fidelity

B. OPTIMIZATION MECHANISMS OF DIGITAL TOOLS ON INHERITANCE PATHWAYS

Digital tools optimize inheritance pathways through three mechanisms: cognitive load decomposition, feedback loop shortening, and learning resource aggregation. The cognitive load decomposition mechanism breaks complex skills into independently practicable micro-units. Virtual reality systems support learners focused repetitive training on single actions, reducing cognitive pressure of simultaneously processing multiple elements, conforming to the chunking principle in cognitive psychology. Comparative experiments show that experimental groups using VR step-by-step training had 32% higher retention rates in memory of complex action sequences than control groups using traditional holistic teaching ($t = 4.217$, $p < 0.01$). The feedback loop shortening mechanism relies on real-time sensor monitoring, with learners receiving deviation data immediately after each action execution. Delayed feedback from masters' oral instruction after observation in traditional modes is replaced by millisecond-level digital feedback. Experimental data show that experimental groups using motion capture systems required 41% fewer training repetitions to reach skill standards compared to control groups. The learning resource aggregation mechanism integrates scattered teaching content

through cloud platforms, enabling learners to access demonstration videos from multiple inheritors across geographical limitations, promoting comprehensive understanding of knowledge [13]. However, optimization effects vary by skill type. For wrestling (Bokh), which depends heavily on tactile force perception, the experimental group achieved 79.6% precision versus the control group's 83.2%—a modest 4.3% gap. This suggests that while virtual technology cannot fully replicate the nuances of body-to-body contact, motion capture systems adequately convey basic movement patterns and weight distribution principles. The precision deficit is smaller than the cultural fidelity gap (61.5% vs 76.3%), indicating that technical elements translate better to digital formats than contextual dimensions.

C. COMPARATIVE EMPIRICAL RESEARCH ON TYPICAL CASES

1) Research Design and Sample Selection Strategy

A retrospective research design is adopted, selecting groups participating in learning three types of ethnic traditional sports skills—martial arts, wrestling, and archery—from January 2022 to June 2024 as research subjects. Sample selection follows the principle of methodological diversity: for martial arts, 30 Tai Chi learners using VR teaching platforms (experimental group) and 30 Baguazhang learners in traditional master-apprentice systems (control group) are selected; for wrestling, 30 Mongolian wrestling learners participating in online teaching (experimental group) and 30 participants in offline Naadam inheritance activities (control group); for archery, 30 trainees using motion capture technology (experimental group) and 30 maintaining traditional ritual inheritance (control group). All participants are aged 18–35 with identical learning starting points and uniform 6-month learning cycles. Data from three assessments at learning start point, 3-month mid-point, and 6-month end point are retrospectively collected, comprehensively gathering information on four-dimensional inheritance efficiency indicators. This study was approved by the Ethics Committee of Nanchang Institute of Technology, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

2) Data Collection Methods and Measurement Tools

Data collection employs a trinity method of objective measurement, subjective evaluation, and process tracking. At the objective measurement level, high-speed camera systems (240 fps) record learners' action performance. OpenPose pose estimation algorithms extract coordinates of 17 key skeletal points. This measurement approach reflects the philosophical assumption that bodily movements can be fully captured through spatial coordinates. By reducing complex skills to Euclidean distances between joint positions, the assessment privileges geometric accuracy over embodied qualities. While this quantification enables objective comparison, it inherently favors skills with clear spatial parameters (strikes, stances) over those emphasizing subtle energetic qualities (force modulation, breath integration). Euclidean distance deviations from standard actions are calculated to quantify inheritance precision. At the subjective evaluation level, a review panel of 5 national-level inheritors is invited to assess learners according to unified standards for action standardization (40 points), cultural understanding (30 points), and overall coordination (30 points). Cultural cognition questionnaires are administered (reliability coefficient α = 0.89). At the process tracking level, learning log systems record training duration and frequency. For experimental groups, digital platform usage data undergoes embedded point collection to obtain behavioral data such as function usage frequency and learning paths. All data undergo standardization processing and are imported into SPSS 26.0 for statistical analysis, ensuring reliability of research conclusions.

3) Comparative Analysis and Difference Testing of Inheritance Efficiency

Comparative analysis reveals differentiated effects of digital inheritance across dimensions (see Table 2). In the inheritance speed dimension: experimental group average learning cycle is 4.2 months, control group 5.8 months, shortened by 27.6% ($t = 3.847$, $p < 0.01$), with VR instant feedback mechanisms significantly accelerating action memory formation. In the inheritance precision dimension: experimental group action restoration rate mean is 82.3%, control group 85.7%, difference not significant ($t = 1.203$, $p > 0.05$), indicating digital means can reach traditional method levels in action accuracy. In coverage breadth dimension: experimental groups reached 873 exposures (views/interactions) through online platforms, while control groups engaged 47 participants in sustained practice. While digital platforms achieve wider dissemination reach, this metric measures initial contact rather than deep transmission—only a small fraction of online viewers progress to systematic skill acquisition. Thus, the 18.6-fold expansion represents potential reach, not equivalent transmission depth. In cultural fidelity dimension: control group score is 78.6 points, experimental group 64.2 points, showing significant difference ($t = 4.921$, $p < 0.001$), with digital inheritance notably insufficient in ritual context reproduction and cultural narrative completeness. Variance analysis shows skill type has moderating effects on inheritance efficiency ($F = 5.632$, $p < 0.05$). For martial arts with high action complexity, digitalization advantages are more obvious; for archery involving strong ritualism, traditional methods show higher fidelity (see Figure 3).

V. STRATEGY SYSTEM FOR INHERITANCE EFFICIENCY OPTIMIZATION AND TECHNICAL IMPLEMENTATION PATHWAYS

A. PRECISION INHERITANCE MODEL DESIGN EMPOWERED BY INTELLIGENT TECHNOLOGY

A precision inheritance model based on data-driven, intelligent adaptation, and dynamic optimization is constructed,

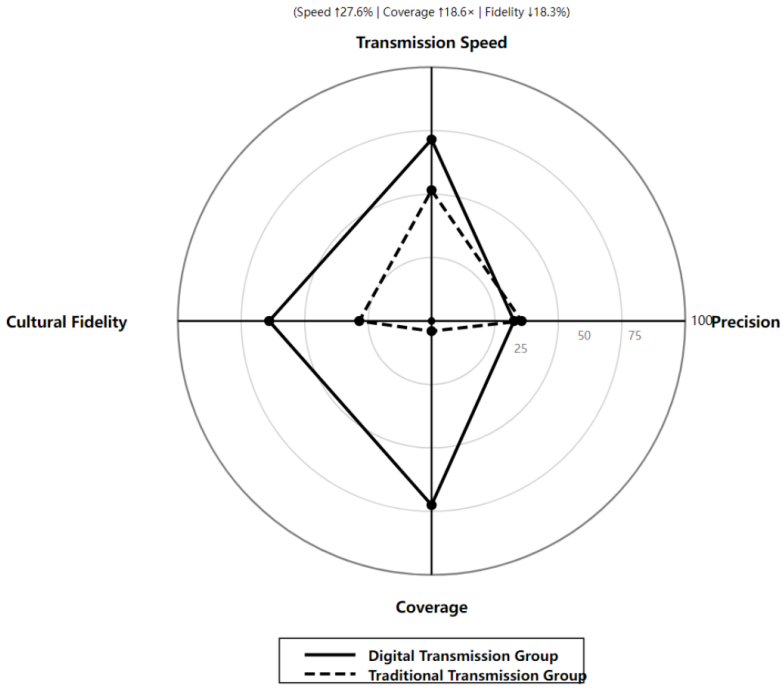

FIGURE 3. Radar Chart of Four-Dimensional Indicators of Inheritance Efficiency

overcoming the limitations of traditional one-size-fits-all teaching. The data-driven layer establishes individual profiles based on learners' physiological, behavioral, and cognitive data. Wearable devices collect physiological indicators such as heart rate variability and muscle fatigue to determine optimal training intensity and rest cycles. Eye-tracking technology analyzes attention distribution patterns to identify confusion points in learning processes. The intelligent adaptation layer uses machine learning algorithms to generate customized learning plans. Collaborative filtering recommendation algorithms suggest optimal training sequences for novices based on similar learners' successful paths. Reinforcement learning models dynamically adjust training difficulty; when the system detects a learner's skill mastery exceeds 85%, it automatically pushes advanced content. The dynamic optimization layer achieves iterative improvement through continuous feedback, with weekly learning effectiveness assessments comparing actual progress with expected goals and using genetic algorithms to optimize teaching parameters. A Tai Chi training institution applying this model reduced average student attainment time from 8.3 months to 5.7 months, with skill retention rates improving by 29%, validating precision inheritance effectiveness.

B. COLLABORATIVE INTEGRATION FRAMEWORK OF TRADITIONAL MASTER-APPRENTICE SYSTEM AND DIGITAL PLATFORMS

An offline core–online extension dual-track collaborative framework is proposed to leverage complementary advantages of traditional and modern inheritance methods. The offline core track retains traditional face-to-face master-apprentice interaction, undertaking three core functions: bodily perception cultivation through masters' hands-on adjustment of learners' muscular states, transmitting force textures and breathing rhythms that digital devices cannot replicate; cultural immersion education by narrating skills' historical origins and ethical norms in ritualized scenes, establishing learners' cultural identification with skills; emotional bond construction through long-term master-apprentice relationships forming trust and belonging, strengthening learning motivation and inheritance responsibility. The online extension track uses digital platforms to expand inheritance's spatiotemporal boundaries, performing four auxiliary functions: fragmented knowledge supplementation enabling learners to watch action essential micro-videos during commutes, accumulating theoretical knowledge; virtual scene simulation rehearsing complex actions in VR environments, reducing injury risks in actual training; community mutual assistance learning where learners exchange insights and correct each other in online forums, forming peer support networks; dissemination and promotion marketing attracting potential learners through short video platforms. The key to dual-track collaboration lies in establishing effective connection mechanisms: assigning online practice tasks after offline courses, with masters reviewing learners' uploaded practice videos before next courses to prepare targeted teaching content [14].

C. DYNAMIC BALANCE MECHANISM BETWEEN CULTURAL GENE PROTECTION AND INNOVATIVE DEVELOPMENT

A core preservation–peripheral innovation stratified protection strategy is established to seek dynamic balance between cultural inheritance and temporal adaptation. The core preservation layer identifies immutable cultural genes of skills, including core rituals embodying ethnic historical memory, behavioral taboos carrying ethical norms, and symbolic systems reflecting cosmological concepts. These elements constitute skills' cultural identity markers requiring strict authenticity maintenance [15]. A cultural gene sequencing method is adopted to organize participatory discussions among inheritors, cultural scholars, and community representatives. The Delphi method identifies core cultural elements of skills to form protection lists. A documentation system records the established forms of core ritual elements as reference baselines, while recognizing that living traditions evolve organically through community practice. Major proposed modifications to core elements are reviewed through deliberative consultation among inheritors, cultural scholars, and community representatives, seeking consensus rather than rigid voting thresholds. This approach balances preservation of cultural integrity with the inherent dynamism of living traditions. The peripheral innovation layer encourages adaptive adjustments of non-core elements, including scientific improvements of training methods, artistic enhancements of performance forms, and modern translations of dissemination discourse. These innovations enhance skills' temporal attractiveness without damaging cultural essence. An innovation sandbox mechanism is established to support experimental projects that encourage young to explore innovative forms. These projects combine traditional martial arts with modern dance and electronic music, while successful cases are selected through market feedback and expert review. Dynamic balance requires establishing assessment feedback mechanisms, regularly monitoring cultural fidelity indicators of skill inheritance. When fidelity falls below warning threshold ($F < 65$), cultural restoration procedures are initiated (see Table 3).

TABLE 3. Stratified Strategy for Cultural Gene Protection and Innovation

Level	Element Type	Protection Strategy	Innovation Space	Regulatory Mechanism
Core Layer	Core Ritual Procedures	Documentation with flexibility	Consensus-based review for major changes	Community deliberation + expert consultation
	Ethical Behavioral Norms	Strict inheritance (rigid)	Interpretation innovation only	Inheritor certification assessment
	Ethnic Symbol Systems	Complete preservation (mandatory)	No commercial abuse	Intellectual property protection
Peripheral Layer	Training Methods & Techniques	Encourage scientific improvement	Highly open	Effectiveness evaluation verification
	Performance Form Design	Support artistic enhancement	Moderately open	Expert review + market testing
	Dissemination Discourse System	Promote modern translation	Completely open	Cultural consultation review

Data source: Based on protection practice experience summary of 8 ethnic sports projects (2020–2024).

VI. CONCLUSION

The impact of digital technology on ethnic traditional sports skills and production techniques is both structural and systemic, bringing significant improvements in inheritance efficiency alongside deep concerns about the cultural fidelity of these embodied practices. Research reveals that digital media embedding causes skill structure to evolve from organic wholes to modularized components, inheritance networks to reconstruct from hierarchical trees to distributed networks, and cultural fields to migrate from regional embedding to virtual spaces. The constructed four-dimensional efficiency measurement model and intelligent evaluation algorithm provide scientific tools for quantitative evaluation. Empirical research confirms that digital tools achieve remarkable results in speed and coverage improvements but have obvious deficiencies in cultural context immersion. Future inheritance practice should adhere to dual-track parallel principles, preserving the cultural core of master-apprentice bodily interaction while leveraging dissemination advantages of digital platforms. With the development of frontier technologies such as artificial intelligence and brain-computer interfaces, the inheritance of traditional skills and movement patterns will face profound transformations, requiring continuous tracking of technological impacts on cultural transmission within metaverse environments to promote the sustainable prosperity of these tactile crafts in digital civilization.

AUTHOR CONTRIBUTIONS

Conceptualization –Zhijun Li and Guofeng Deng; methodology –Zhijun Li and Guofeng Deng; investigation – Zhijun Li and Guofeng Deng; writing-original draft preparation – Zhijun Li and Guofeng Deng. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

[1] B. Xu and J. Wang, "Advancement dilemmas and practical paths of digital empowerment for intangible sports heritage protection and inheritance," Hubei Sports Science and Technology, vol. 44, no. 06, pp. 76-80+112, 2025, doi: 10.20185/j.cnki.1003-983X.2025.06.012.

[2] R. Li, "The interweaving of folk sports and textile printing: skill transformation from tradition to modernity," Textile Auxiliaries, vol. 42, no. 10, pp. 72-75, 2025.

[3] W. Wu, "Revitalization and cultural innovation of ethnic traditional sports based on deep learning models," Applied Mathematics and Nonlinear Sciences, vol. 9, no. 1, 2024, doi: 10.2478/AMNS.2023.2.01016.

[4] B. Qian, "Strategies for informational integration of Wushu teaching and ethnic traditional sports culture," Applied Mathematics and Nonlinear Sciences, vol. 9, no. 1, 2024, doi: 10.2478/AMNS-2024-2835.

[5] E. Chen, "Research on the diffusion and evolution of ethnic traditional sports culture based on spatial diffusion modeling," Applied Mathematics and Nonlinear Sciences, vol. 9, no. 1, 2024, doi: 10.2478/AMNS-2024-3288.

[6] X. Ye and L. Luo, "Exploration on the motivating factors and promotion mechanism for the footprint sharing of traditional sports in the Tibetan-Yi Corridor in the digital era," Educational Innovation Research, vol. 3, no. 4, pp. 143-148, 2025, doi: 10.18063/EIR.V3I4.1013.

[7] Z. Chen and D. Tan, "Passing the torch and composing new chapters: research on living inheritance of ethnic minority sports equipment manufacturing skills in China," Journal of Guangzhou Sport University, vol. 45, no. 02, pp. 11-19, 2025, doi: 10.13830/j.cnki.cn44-1129/g8.2025.02.002.

[8] Wurigenmuren, S. Liu, and B. Chultem, "Research on the construction and guardianship of Inner Mongolia Minzu sports resource database in cloud computing environment," Applied Mathematics and Nonlinear Sciences, vol. 10, no. 1, 2025, doi: 10.2478/AMNS-2025-0713.

[9] C. Juan and X. Li, "Exploration on the application of neural network technology in the protection and inheritance of ethnic traditional sports culture," Applied Mathematics and Nonlinear Sciences, vol. 10, no. 1, pp. 20251008-20251008, 2025, doi: 10.2478/AMNS-2025-1008.

[10] X. Lin, "Research on contemporary inheritance of Chinese traditional arts from an industrial perspective," Southeast University; 2024, doi: 10.27014/d.cnki.gdnau.2024.000525.

[11] H. Sima, J. Dai, and X. Peng, "Research on digital transformation of sports intangible cultural heritage empowered by new quality productive forces," Journal of Shenyang Sport University, vol. 43, no. 04, pp. 8-15, 2024.

[12] R. Zhou, C. Wang, and Y. Mei, "The value and application of minority characteristic sports apparel in the dissemination of minority traditional sports culture," Journal of Sociology and Ethnology, vol. 6, no. 2, 2024 , doi: 10.23977/JSOCE.2024.060204.

[13] B. Zheng, "SWOT analysis of traditional ethnic group sports development in Ganzi Prefecture," Frontiers in Sport Research, vol. 6, no. 1, 2024 , doi: 10.25236/FSR.2024.060116.

[14] W. Ye and S. Li, "Digital protection analysis of national traditional sports health cultural heritage based on big data in the era of data cloud," Multimedia Tools and Applications, vol. 83, no. 27, pp. 69739-69758, 2024, doi: 10.1007/S11042-024-18371-0.

[15] B. Yang and N. Gong, "Research on the development strategy of ethnic traditional sports based on optimization theory," Applied Mathematics and Nonlinear Sciences, vol. 9, no.1, 2024, doi: 10.2478/AMNS.2023.2.00918.