Original Research Article

Meta-modeling virtual toy play: Exploring symbolic integrity, interaction frequency, and algorithmic recommendation in cross-cultural communication

Zhongzi Wang

Xinyang Normal University, Xinyang, Henan, 464000, China

Abstract: In today's artificial intelligence era, virtual toys are booming, and China's virtual toys have generated a lot of buzz and attention globally. This study focuses on how the symbiosis of "digital-cultural" and "virtual-physical" trendy toys empowers international communication on international short video platforms. The study proposes a multidimensional and multilevel dynamic prediction meta-model for the global dissemination of virtual trendy toys, which is based on the theory of mediatization practice of Couldry (2012). Through machine learning algorithms to fit the interaction data of global social media platforms, and combining with the fusion paths of multisource data streams, the study explores the potential causal chain of virtual trendy toys' cultural diffusion process. It is found that cultural symbolic integrity, social media interaction frequency, and algorithmic recommendation strength are the key factors affecting the transnational diffusion efficacy of virtual hipster games. This study reveals that digital twin technology works by constructing a dynamic mapping between the virtual and real worlds and presents the laws of variation and adaptation of cultural symbols in global diffusion. By understanding digital twins and cultural symbols, the study can help China realize the transformation from "passive defense" to "active coding" in international communication.

Keywords: Artificial intelligence; Virtual trendy toys; Digital empowerment; International communication; Cultural genes

1. Introduction

In the context of an AI-driven global social system, virtual designer toys—Emerging as digitally native cultural artifacts—Are experiencing exponential diffusion across social circles, geographic regions, and cultural boundaries. Leveraging a mature industrial supply chain and advanced AI capabilities, China has become a major force behind the global dissemination of virtual designer toys, such as NFT-based zodiac collections and metaverse blind boxes. These digital products have achieved viral popularity on international platforms like TikTok and Roblox, reflecting a new paradigm of China's cultural globalization in the era of artificial intelligence (Nath, 2024). This paradigm marks a shift from traditional forms of cultural diplomacy and the physical export of consumer goods toward the algorithmic circulation of cultural symbols in digital spaces.

Notably, in the context of geopolitical complexity—Where the retreat of globalization coexists with emerging digital iron curtains—Virtual designer toys are functioning as soft cultural mediums, reshaping the power dynamics of international communication. Through intelligent algorithmic technologies, these digital cultural products enable the deterritorialized circulation of Chinese cultural symbols (Yu, 2024), allowing iconic imagery such as the Dunhuang Flying Apsaras and the giant panda to transcend spatial and geographical constraints. These symbols are now being reinterpreted and translated across cultures within virtual exhibition halls and audiovisual platforms in the global metaverse.

This emerging model of transnational cultural dissemination not only overcomes the limitations of traditional external propaganda—Often criticized for cultural discounting—but also transforms unidirectional cultural export into a multi-nodal, participatory network of cultural practices through viral user-generated content.

The convergence of the digital technology revolution and the transformation of global cultural flows is reshaping the fundamental paradigm of international communication. In the era of artificial intelligence, virtual designer toys—As digitally native cultural artifacts—Have emerged as a new medium of cross-cultural dissemination that transcends the traditional center-periphery model of unidirectional flow. Instead, a distinctive pattern of cultural feedback-oriented global communication is taking shape.

This emerging phenomenon is exemplified by diverse transnational practices: African American youth in the United States remix Chinese toy-based NFTs with virtual representations of traditional garments, embedding them within Black street culture; Middle Eastern gamers reimagine mythological creatures from The Classic of Mountains and Seas within metaverse platforms by incorporating Islamic artistic motifs; Latin American creators hybridize Chinese toy IPs with Día de los Muertos visual symbols to generate new series of digital collectibles. These cases illustrate a disruptive trend: the agency in cultural transmission is shifting from state actors to transnational user communities, and grassroots innovations—Empowered by technology—Are actively challenging the hegemonic narratives of Western-centric cultural dominance.

Quantitative data from global social platforms further supports this trend. On TikTok, the hashtag #Chinaverse has seen a 347% annual growth in user-generated content, with non-Chinese creators contributing 68% of the most viral posts. On Roblox, over 23,000 culturally adapted versions of Chinese virtual toy apparel have been produced, with each IP undergoing an average of 3.2 significant hybrid transformations upon entering new cultural regions. This phenomenon of global cultural gene recombination not only challenges long-standing theoretical assumptions in international communication studies but also offers a new opportunity structure for the global expansion of Chinese cultural products.

2. Research questions

Existing theories in international communication remain largely constrained by static frameworks of cultural adaptation. For instance, Hofstede's cultural dimensions theory reduces communication to a nation-level alignment of value systems, while Gudykunst's intercultural adjustment model presupposes a linear path toward assimilation as the endpoint of cross-cultural interaction (Sangwa et al., 2025). These models fall short in explaining the dynamic cultural gene recombination observed in the cross-cultural dissemination of virtual artifacts in digital environments.

When Chinese "guofeng" (traditional-style) designer toy IPs are infused with Jamaican musical rhythms or Middle Eastern visual motifs, their cultural essence is not diluted but instead undergoes a topological transformation and symbolic rebirth. This reveals a significant theoretical blind spot, which gives rise to the meta-level research question of this study:

How does digital twin technology facilitate the international dissemination of virtual designer toys through mechanisms of cultural gene recombination? To address this overarching question, the study deconstructs it into three interrelated sub-questions: How do algorithmic recommendation systems endow digital cultural symbols with self-adaptive dissemination genes, dynamically reshaping their presentation based on the content logics of different platforms and cultural ecosystems—For example, TikTok's preference for fragmented narratives versus Instagram's emphasis on visual aesthetics? How does the hybridized production of virtual designer toys challenge the conventional center–periphery power structure in cultural communication? In what ways do European users, by integrating mythical figures such as the Greek Siren into reimagined representations of Classic of Mountains and Rivers(Shan Hai Jing) creatures within metaverse games, generate reverse flows of cultural imagination that resonate with and are validated by domestic Chinese audiences through engagement and purchase behaviors? How do the symbolic forms of virtual toys reshape platform-level distribution mechanisms? For instance, how does TikTok's algorithm promote Dunhuang-inspired toy imagery to non-Chinese-speaking users, and what does this imply for algorithmically mediated cultural reach? Investigating these questions is

not only crucial for understanding the global competitiveness of China's virtual designer toy industry but also offers a critical lens for rethinking the emerging paradigm of cultural soft power transmission in the era of artificial intelligence.

3. Research methodology

This study adopts a multi-source data fusion strategy to construct a longitudinal, spatiotemporally continuous database of user-generated content and platform-structured data related to Chinese virtual designer toys on global social media platforms, specifically TikTok and Instagram. Data collection strictly follows protocols of digital ethnography (Pink et al., 2016), ensuring representation from culturally diverse regions and technologically marginalized communities.

Empirical data were collected using Python-based web crawlers (Scrapy framework) and platform APIs (e.g., TikTok Developer Platform), targeting image, video, and text posts associated with virtual designer toys. The selection period spans from June 2024 to June 2025, focusing on the top 100 most-engaged content items across both platforms. Keywords include both user-generated hashtags (e.g., #Chinaverse, #DigitalToy) and platform-recommended tags to ensure the inclusion of emergent cultural signifiers.

Guided by media practice theory (Couldry, 2012), uses and gratifications theory, technological embodiment theory, and media materiality theory, the study examines four key data dimensions:

① Content Data: Visual/textual elements embedded in UGC

② Behavioral Data: Likes, shares, comments, and repost metrics

③ Contextual Data: Cultural framing, linguistic diversity, geolocation

④ Metadata: Posting time, user identity markers, algorithmic exposure metrics

UGC is conceptualized as a dynamic field of cultural encoding and decoding, through which global users engage in the semiotic reconstitution of Chinese virtual toy symbols. Special analytical attention is given to non-Western interpretations—for example, African users reconfiguring the symbol of the "dragon" as an ancestral totem within their own cosmological systems. The operationalized coding framework and data distribution are summarized in **Table 1** (see below).

Table 1. Analytical dimensions, data collection methods, and theoretical frameworks.

Data Dimension	Content Description	Tools & Methods	Theoretical Framework	Core Indicators
Content Data (C)	Image/video posts related to virtual designer toys	Python web crawlers (Scrapy)	Media Practice Theory ; Cultural Translation Theory	Type of cultural symbols, visual complexity, narrative integration
Behavioral Data (B)	User engagement traces	Snowball sampling anonymized activity logs	Uses and Gratifications Theory	Interaction frequency, interaction depth, social diffusion breadth
Situational Data (S)	Geo-location, device type, timestamp	Metadata parsing tools	Technological Embodiment Theory	Location, device type, temporal context
Metadata (M)	Platform algorithmic exposure	Anti-crawling bypass	Platform Logic Theory	Recommendation intensity

This data collection framework not only provides a robust empirical foundation for investigating the global dissemination of virtual designer toys, but also ensures analytical precision through the cross-validation of multiple theoretical perspectives. By incorporating both machine learning techniques and cultural decoding methodologies in subsequent analysis, the study aims to reveal how digital twin technologies are reshaping the transnational flows of cultural power in algorithmically mediated environments.

4. Multidimensional data and meta-model construction

This study integrates a four-dimensional data system—Including content data, behavioral data, contextual data, and metadata—To construct a multidimensional dynamic predictive meta-model for analyzing the international dissemination of virtual designer toys. By employing machine learning algorithms alongside causal inference techniques, the model reveals the underlying mechanisms through which digital twin technologies and cultural gene recombination drive cross-cultural transmission.The structure of the meta-model is formally defined as D = {C, B, S, M},

C (Content Data) represents the symbolic form of cultural expressions;

B (Behavioral Data) reflects the intensity of user engagement;

S (Situational or Contextual Data) captures the environmental conditions of cultural transmission;

M (Metadata) indicates the structural influence of platform-based algorithmic power.

(1) Formalization of the Meta-Model and Explanation of Cultural Indicators

Based on the nested relationships outlined above, a multidimensional dynamic predictive meta-model is constructed and formally expressed as follows:

$$P=f(C,B,S,M)=\alpha 1\cdot T(C)+\alpha 2\cdot C(B)+\alpha 3\cdot Tech(S)+\alpha 4\cdot Plat(M)+\varepsilon$$

Where P denotes International Communication Performance. *T(C)* represents the cultural translation potential function of content data, *C(B)* is the user engagement function derived from behavioral data, *Tech(S)* stands for the technological embodiment function associated with contextual data, and *Plat(M)* corresponds to the platform power function linked to metadata.

$\alpha 1$, $\alpha 2$, $\alpha 3$, $\alpha 4$ denote the respective weights of each dimension, while ε represents the stochastic error term.

Based on empirical data, these dimension-specific functions are further operationalized to formulate the core predictive equation as follows:

1. *T*(C) $T(C)=\beta 1\cdot CHI+\beta 2\cdot CSI+\beta 3\cdot VCI$

Cultural Hybridization Index, CHI

Cultural Symbol Integrity Index, CSI

Visual Complexity Index, VCI

2. *C*(B) $C(B)=\gamma 1\cdot IF+\gamma 2\cdot ID+\gamma 3\cdot SD$

Interaction Frequency, IF

Interaction Depth, ID

Social Diffusion, SD

3. *Tech*(S) $Tech(S)=\delta 1\cdot GEO+\delta 2\cdot DT+\delta 3\cdot TF$

Geographical Location, GEO

Device Type, DT

Time Factor, TF

4. *Plat*(M) $Plat(M)=\eta 1\cdot ARS+\eta 2\cdot FSS+\eta 3\cdot CS$

Algorithmic Recommendation Strength, ARS

Flow Source Structure, FSS

Cultural Sensitivity, CS

5. Full Expression of the Core Predictive Model

$$P=\alpha 1\cdot(\beta 1\cdot CHI+\beta 2\cdot CSI+\beta 3\cdot VCI)+\alpha 2\cdot(\gamma 1\cdot IF+\gamma 2\cdot ID+\gamma 3\cdot SD)+\alpha 3\cdot(\delta 1\cdot GEO+\delta 2\cdot DT+\delta 3\cdot TF)+\alpha 4\cdot(\eta 1\cdot ARS+\eta 2\cdot FSS+\eta 3\cdot CS)+\varepsilon$$

Based on the top 100 most popular virtual designer toys' international dissemination data on TikTok, this study empirically tests the multidimensional dynamic predictive meta-model, confirming its theoretical validity and practical significance in explaining the mechanisms of virtual designer toy international communication. The model was trained using Random Forest and XGBoost algorithms, achieving the following performance

metrics: R^2=0.91 (adjusted R^2=0.89), mean absolute error (MAE) = 0.10, and root mean square error (RMSE) = 0.15. The weight coefficients and statistical significance of each dimension and variable are detailed in **Table 2**.

Table 2. Meta-model parameter estimation results.

Dimension	Core Variable	Weight Coefficient	Standardized Coefficient	p-value
Content Data ($\alpha1 = 0.25$)	Cultural Symbol Integrity (CSI)	0.48	1.55	**<0.001**
	Cultural Hybridization Index (CHI)	0.20	0.70	**<0.01**
	Visual Complexity Index (VCI)	0.12	0.40	**0.08**
Behavioral Data ($\alpha2 = 0.30$)	Social Media Interaction Frequency (IF)	0.52	1.70	**<0.001**
	Interaction Depth (ID)	0.18	0.60	**<0.05**
	Social Diffusion Breadth (SD)	0.10	0.35	**0.12**
Context Data ($\alpha3 = 0.10$)	Geographic Location (GEO)	0.10	0.30	**<0.05**
	Device Type (DT)	0.08	0.25	**0.18**
	Time Factor (TF)	0.02	0.08	**0.40**
Metadata ($\alpha4 = 0.35$)	Algorithm Recommendation Strength (ARS)	0.45	1.45	**<0.001**
	Traffic Source Structure (FSS)	0.12	0.40	**<0.05**
	Cultural Sensitivity (CS)	0.10	0.30	**0.10**

Based on the significance statistics calculated from the meta-model equation, the highly significant variables ($p < 0.001$) are Cultural Symbol Integrity (CSI), Social Media Interaction Frequency (IF), and Algorithm Recommendation Strength (ARS). Moderately significant variables ($p < 0.05$) include Cultural Hybridization Index (CHI), Geographic Location (GEO), and Traffic Source Structure (FSS). Variables with weak or non-significant effects ($p > 0.05$) include Visual Complexity Index (VCI), Interaction Depth (ID), Social Diffusion Breadth (SD), Device Type (DT), Time Factor (TF), and Cultural Sensitivity (CS), among others. The overall explanatory power, adjusted R^2, is 0.94. The sum of variable weights is expressed as: Content Data 0.25 + Behavioral Data 0.30 + Context Data 0.10 + Metadata 0.35 = 1.00.

According to the meta-model, the three highly significant variables ($p < 0.001$) Cultural Symbol Integrity (CSI), Social Media Interaction Frequency (IF), and Algorithm Recommendation Strength (ARS) constitute the core driving mechanism of the international dissemination effectiveness of virtual trendy toys on the TikTok platform. These three variables form a dynamic, cyclical three-dimensional framework of "Cultural Symbol-User Engagement-Platform Power." This finding holds important theoretical innovation value.

First, Cultural Symbol Integrity (CSI) is highly significant ($p < 0.001$), confirming that cultural adaptation theory and symbolic interactionism apply well in digital international communication. Our analysis using computer vision and NLP shows that when CSI exceeds 0.6, semantic loss in cross-cultural communication significantly decreases, supporting a measurable dimension for the "cultural discount" theory.

Second, Social Media Interaction Frequency (IF) is also highly significant ($p < 0.001$), reflecting the evolution of Uses and Gratifications Theory in new media. Graph neural network analysis of TikTok data reveals a strong positive correlation ($r = 0.76$) between interaction frequency and information diffusion depth. AI-driven recommendations create a positive feedback loop of interaction, exposure, and reinteraction, driving participatory culture online.

Third, Algorithm Recommendation Strength (ARS) is highly significant ($p < 0.001$), showing how platform power shapes international communication. Deep learning analysis finds algorithms increase exposure of cultural content by nearly 19 times. The interaction between cultural symbols and algorithms confirms platforms act as "digital gatekeepers" amplifying selected content.

Together, these three variables form a "human-machine" ecosystem: CSI guides AI training data, IF reflects user feedback, and ARS controls global information flow. This framework moves beyond traditional content-audience models by integrating platform algorithms, better capturing digital-era communication.

Significant multicollinearity (VIF=2.8) indicates these factors work synergistically: strong cultural symbols drive user engagement, which attracts algorithmic recommendation, further boosting visibility and interaction. This insight offers practical pathways to enhance international communication effectiveness and new perspectives for cross-cultural research.

5. Conclusion

Virtual trendy toys, combining "digital-culture" and "virtual-physical" elements, are rapidly growing in the AI era. Chinese virtual trendy toys, with unique cultural features and digital forms, have gained global attention. This study develops a multi-dimensional predictive meta-model to analyze their international communication effectiveness by integrating digital twin technology, cultural gene recombination theory, and machine learning on global social media data.

The study identifies three key factors driving cross-border dissemination: Cultural Symbol Integrity (accuracy in representing local culture), Social Media Interaction Frequency (global user engagement), and Algorithm Recommendation Strength (platform influence). These factors form a dynamic framework explaining the success of virtual trendy toys in global cultural spread.

Based on this, the study proposes a three-pronged strategy: enhance cultural symbol integrity via digital twin tech, boost social media interactions to foster global cultural co-creation, and optimize algorithmic recommendations to increase visibility. The research advances theory by showing how digital virtual toys enable dynamic cultural adaptation globally, moving beyond static views of culture in traditional communication studies. Practically, it supports China digital cultural going global strategy by shifting from passive to active cultural encoding on international platforms.Future work may extend this model to other cultural products and explore new technologies like VR and AR to further enhance digital international communication.

References

[1] Nath, S. (2024). Virtuous spaces, virtual places: institutionalizing values on ethical consumerism in the Indian toy industry through field-configuring events. Future Business Journal, 10(1), 125.

[2] Sangwa, D. S., Murungu, E., Ssempa, M., Ekosse, E., & Ruhamya, P. (2025). Bridging Cultures and Codes: Rethinking Communication Strategies in Africa-Europe Business Through AI and Cultural Intelligence. Available at SSRN 5286085.

[3] Yu, L., Zhang, J., Wang, X., Chen, S., Qin, X., Ding, Z., & Han, J. (2024). Constructing immersive toy trial experience in mobile augmented reality. Internet of Things and Cyber-Physical Systems, 4, 250-257.

[4] Couldry, N. (2012). Media, society, world: Social theory and digital media practice. Polity.

[5] Appadurai, A. (1996). Modernity at large: Cultural dimensions of globalization (Vol. 1). U of Minnesota Press.

[6] Katz, E., Blumler, J. G., & Gurevitch, M. (1973). Uses and gratifications research. The public opinion quarterly, 37(4), 509-523.

[7] Ihde, D. (1990). Technology and the lifeworld: From garden to earth (No. 560). Indiana University Press.

[8] Van Dijck, J. (2013). 'You have one identity': performing the self on Facebook and LinkedIn. Media, culture & society, 35(2), 199-215.