

A Study on Narrative Expression and Audience Engagement in Museum Exhibition Design from the Perspective of Interaction Design

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ABSTRACT Museum exhibition design often suffers from fragmented narrative logic and one-way information interaction, leading to a mismatch between exhibition narrative value and audience engagement depth. To address this issue, this paper constructs a narrative exhibition design framework from the perspective of interaction design. By establishing an interaction model of information flow, behavior flow, and emotional flow, the study proposes a system optimization path based on user behavior data and spatial feedback loops. Eye-tracking and behavior recording technologies are used to collect browsing paths and dwell times from 120 visitors in different exhibition areas, forming an interactive behavior database. A multidimensional interaction matrix is then established based on content narrative nodes and audience behavior responses, and cluster analysis and weight allocation are applied to optimize the narrative structure. Prototype exhibition interface testing is conducted, and facial recognition and questionnaires are used to evaluate changes in audience emotion. The results show that the optimized exhibition model increases average visitor dwell time by 32.5% and interaction triggers by 40.7%, verifying the effectiveness of interaction design in narrative expression and participation enhancement.

INDEX TERMS interaction design, museum exhibition, narrative expression, audience engagement, behavioral sensing

I. INTRODUCTION

A. RESEARCH BACKGROUND AND PROBLEM STATEMENT

MUSEUM exhibition design suffers from numerous logical breaks and information delays in expressing the narrative of evolution, leading to poor continuity in the spatial and temporal presentation of weaving traditions and fabric craftsmanship. This lack of cohesive storytelling regarding history results in a fragmented experience where visitors lack clear direction for navigating the complex transitions between historical loom technologies and modern garment aesthetics. The transmission of narrative information within the museum relies heavily on linear displays and passive reading. The integration of digital media and interactive interfaces is low, and visitors' participation in the information perception process is limited to one-way reception.

The fragmentation of narrative logic makes it difficult for the exhibition content to form a complete information chain. The connection between interactive elements and exhibition themes is unstable, which reduces the depth of audience psychological participation. Interactive installations mostly remain at the level of formal triggering and mechanical re-

sponse, lacking a data feedback system based on behavioral analysis. The existing exhibition model lacks a closed-loop verification path at the level of interaction design (IXD) strategy, and the logical mapping relationship between audience participation and information dissemination is unclear, resulting in weakened narrative expression and a break in the experience.

B. SIGNIFICANCE OF THE RESEARCH

The IXD theory emphasizes the dynamic coupling between users, interfaces, and context, enabling exhibition content to form a continuous narrative in interactive responses. This promotes the synergistic effect between information, emotion, and behavior, thus shifting the exhibition narrative from passive presentation to active construction based on behavioral data, making the audience experience process quantifiable and iterable. The value of this study lies in using the systematic thinking of design methodology to reconstruct the narrative structure, transforming the interaction logic into the organizational basis of spatial structure and information hierarchy. By integrating behavioral data collection, emotional response recognition, and information feedback mechanisms, a dynamic mapping of user partici-

pation in exhibition design is achieved.

The introduction of IxD prompts the audience to complete information encoding and emotional extension in interactive behavior, and the narrative path forms a real-time adjustment mechanism.

C. RESEARCH OBJECTIVES AND CONTENT

This project aims to analyze the interaction logic between visitors and the exhibition system using interactive design (IxD) and a multi-dimensional data-driven approach, thereby achieving dynamic feedback for both visitors and the exhibition system. It unfolds across three levels: “spatial perception, behavioral response, and emotional change,” using the triggering elements of visitor behavior as the main thread to construct bidirectional links between story nodes, ensuring consistency between the exhibition content and the experiential rhythm.

The research mainly focuses on the quantitative analysis of interactive behavior data and emotional feedback mechanisms regarding user engagement with aesthetic designs. Eye-tracking and facial recognition technologies are used to obtain visitors' browsing paths, dwell time, and facial expressions. A behavioral association model is established based on data distribution patterns. Clustering algorithms are used to obtain the response patterns of narrative nodes, and the exhibition structure is allocated according to weights so that behavioral feedback and narrative logic are mutually mapped.

The research and verification phase used an interactive prototype system as a testing platform. Through multiple rounds of audience experiments, the frequency of information triggering and the depth of participation were measured. The changes in emotional investment before and after optimization were compared, and the interactive effect after the narrative design optimization was quantitatively demonstrated.

II. RELATED WORK

A. CURRENT STATUS OF RESEARCH ON NARRATIVE IN MUSEUM EXHIBITIONS

Existing studies have focused on the thematic layering and visual sequence of exhibition content, but there are gaps in context transition and information loss, resulting in a lack of dynamic trend in narrative transmission [1,2]. Most spatial narrative models are based on physical layout and exhibit arrangement, and the structural expression still appears in a static form, lacking emotional guidance and behavioral interaction. With the increasing popularity of digital display, the focus of narrative research has shifted to the interaction and response in the human-exhibition relationship, and the narrative rhythm is modified through audience behavior data to make the exhibition logic dynamically adaptable [3]. However, existing studies lack quantitative methods in terms of emotional perception dimension and behavioral mapping mechanism, the correlation between narrative design and audience perception data is insufficient, and interactive be-

havior does not form a reverse drive for narrative structure, resulting in weak experience continuity and depth.

B. AUDIENCE PARTICIPATION AND EXPERIENCE RESEARCH

The study on audience participation and experience mainly focuses on the comprehensive analysis of audience interaction behavior data and emotional response mechanisms. It analyzes the perception patterns and cognitive processes of audiences under multi-sensory stimulation by measuring their behavioral paths, gaze points and dwell time in the exhibition environment [4].

The research focus has gradually shifted from static observation to dynamic interaction, emphasizing real-time feedback and response control of the audience experience, and forming a data-driven participation evaluation system.

The research direction of immersive experience theory focuses on the collaborative construction of narrative content and interactive media. It strengthens the presence of spatial narrative through the comprehensive design of visual, auditory and tactile senses, thereby enhancing the audience's emotional investment and perceptual coherence [5].

C. APPLICATION OF INTERACTION DESIGN IN CULTURAL CONTEXTS

Research on the application of IxD in cultural scenarios mainly focuses on the dynamic relationship between digital media, spatial narrative and audience behavior. It realizes the re-dissemination of cultural content and the extension of experience through the construction of interactive mechanisms. The current application form is mainly based on multimedia display, which makes the presentation of cultural information shift from static display to behavior response-driven [6,7].

This type of design enhances the audience's initiative in cultural dissemination, enabling the experiential content to generate differentiated feedback under behavioral triggers, thereby constructing an individualized perceptual path.

D. RESEARCH BREAKTHROUGH POINTS

1) Dynamic Narrative Feedback Mechanism

By using Interaction Design (IxD) to construct a narrative structure that changes with the audience's behavior, the system adjusts the order of information delivery based on dwell time and gaze trajectory, enabling the exhibition content to be dynamically updated in response to behavioral triggers.

2) Behavioral Data Closed-Loop Model

Establish an integrated feedback mechanism for behavior collection and emotion recognition, input audience status data into the narrative system in real time, and adjust information weights through algorithms to achieve adaptive response during the exhibition process.

3) Emotion-Driven Experience Optimization

Using emotion recognition results as the basis for narrative adjustment, the system adjusts the intensity of display and the rhythm of interaction according to changes in emotion, so that emotional feedback and information presentation are linked, thereby enhancing the immersion and continuity of the exhibition experience.

III. METHODS

A. RESEARCH FRAMEWORK AND MODEL CONSTRUCTION

The model uses the audience as the trigger for behavior, collecting visual gaze points, spatial movement trajectories, and interactive behaviors based on a multi-dimensional data perception system. This entire behavioral feedback is then incorporated into the information flow for content control. The information flow starts with the relationships between content nodes, mapping the content and behavioral layers through algorithms to create a controllable information progression and theme within the narrative of the exhibition system. The behavioral flow acts as the mediator in the model, with the audience's physiology and behavior as mediating variables. By recording the audience's interactive habits and spatial responses within the exhibition space, these habits and responses are sequenced over time. The model provides real-time feedback on exhibit status based on behavioral strength and frequency, forming a behavioral distribution matrix. This matrix can then be used to guide how exhibition information is presented—adjusting the rhythm and form of visitor interaction to create a more engaging, human-centered museum experience that aligns interaction design with curatorial intent.

The integration of behavioral flow and information flow enables the numerical mapping of audience dynamic behavior to narrative content, establishing a data foundation for triggering emotional flow [8,9]. Emotional Flow uses physiological signals and facial expression recognition algorithms to model emotional states in real time, enabling the system to adjust its display strategy based on the audience's emotional parameters when pushing information.

The model uses an emotional weighting factor to control the narrative rhythm, maintaining a dynamic balance between content presentation and emotional changes, and constructing an iterative multi-dimensional feedback loop to achieve narrative adaptation and immersive experience extension during the exhibition process.

B. DATA ACQUISITION AND SAMPLE DESCRIPTION

A sample of 120 participants with varying exhibition viewing experiences was selected to ensure diversity in behavioral distribution and comprehensiveness in data structure. The experimental setting was a multi-dimensional experiential environment corresponding to the exhibition's narrative space, and data was acquired synchronously using an eye-tracking system and behavioral recording devices. This study was approved by the Ethics Committee of Shanghai

Art & Design Academy, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

Eye-tracking data includes gaze coordinates, dwell time, and scan path, while behavioral data records spatial displacement, number of interaction triggers, and dwell rhythm. Time axis alignment and data accuracy control are achieved through a multi-source synchronization system.

Once the audience enters the experimental space, the behavior monitoring system automatically identifies their individual numbers and initiates data collection. The system captures the audience's gaze trajectory and interactive responses at different narrative points in real time. During the collection process, the system continuously monitors changes in ambient light, sound stimuli, and crowd density to eliminate the influence of interfering variables on information feedback.

Behavioral data enters the central database via a wireless transmission module. After noise removal and data smoothing, an effective sample set is formed and archived in a time-series format, providing a basic data source for narrative node analysis and behavioral pattern recognition.

The sample data eventually formed a two-dimensional matrix of audience visual attention distribution and behavioral dynamic response. The matrix established an association mapping table with each narrative node as an index, which was used to calculate the audience dwell patterns and behavioral preferences [10].

C. DATA ANALYSIS AND MODEL VALIDATION

Data analysis employs a multi-dimensional interaction matrix as a computational tool, fusing audience gaze trajectories, behavioral records, and emotional signals to form a narrative response structure. Guided by narrative nodes, a multi-dimensional data space is constructed to describe the relationship between narrative logic and user behavior through normalized calculations of gaze duration, interaction frequency, and emotional intensity.

Clustering algorithms use the K-means model as the analysis method to identify audience behavior groups by the degree of aggregation of feature vectors in high-dimensional space. In each iteration, the system takes minimizing the intra-class distance as the calculation objective and extracts the common features of different audiences in the behavioral flow and emotional flow to determine the influence distribution of narrative nodes in the audience experience [11,12].

The stability of the matrix calculation results was tested using three indicators: behavioral response rate, emotional consistency, and interaction latency. This verified the applicability of the narrative optimization model in dynamic content adjustment. The process achieved a quantitative match between narrative logic and user feedback.

D. SYSTEM PROTOTYPE AND TESTING PROCESS

The system employs a multi-layered design, distributing visual display, behavioral interaction, and data feedback in parallel to form a simultaneous information flow, behavioral flow, and emotional flow. The interface uses a real-time sensing module to acquire audience operation and gaze information. The exhibition rhythm automatically adjusts based on system dynamic parameters. The information node switching frequency and content display intensity are calculated by the data engine based on audience behavior curves, ensuring uniform narrative rhythm and behavioral response timing. System testing was conducted through a dual-channel approach of emotion recognition and subjective feedback. The facial recognition algorithm uses a Convolutional Neural Network (CNN) to decode subtle facial expressions, extracting emotional intensity parameters and simultaneously inputting them into the emotional flow data layer. Simultaneously, the K-Nearest Neighbors (KNN) algorithm was used for sentiment category clustering analysis. The parameter was set to $K=7$, Euclidean distance was used, the distance weight type was set to distance, the algorithm weight threshold was 0.6, and five-fold cross-validation was used to optimize the classification accuracy. The system adjusts the brightness, semantic depth, and interaction density of the exhibition interface content in real time based on the recognition results, verifying the coupling

stability of emotional feedback and narrative response. After testing, audience subjective evaluations of content rhythm, spatial immersion, and interactive fluency are compared and analyzed with automatically recorded physiological and behavioral data. Emotional change consistency index and behavioral response matching degree are calculated to verify the response efficiency and experience reliability of the narrative optimization mechanism, providing data support for model accuracy correction and system parameter readjustment.

IV. RESULTS AND DISCUSSION

A. BEHAVIORAL DATA

The data collection period was a single narrative process, using second-level timestamps to simultaneously record audience behavior and interactions within the exhibition space. After data cleaning and normalization, the average audience dwell time increased from 246 seconds before the experiment to 326 seconds, a 32.5% increase; the number of triggers increased from 5.9 to 8.3, a 40.7% increase, indicating that the IxD-optimized narrative program has a response time that attracts audience attention and extends engagement time. Table 1 shows the behavioral data statistics and comparisons:

TABLE 1. Behavioral Data Statistics and Comparison

Indicator Categories	Pre-experiment mean	Post-experiment mean	Growth rate	Data source dimensions
Average dwell time (seconds)	246	326	32.5%	Behavioral flow path data
Number of interaction triggers (times)	5.9	8.3	40.7%	Interaction event logging
Behavioral path stability coefficient	0.62	0.81	30.6%	Spatial behavior trajectory
Gaze concentration (%)	68.4	84.7	23.8%	Eye-tracking analysis
Information response synchronization rate	0.57	0.75	31.6%	System log

From the perspective of behavioral paths, the data curves remain consistently stable, with audience behavior density concentrated between narrative nodes, indicating a high degree of coupling between system behavior flow and information flow. The increased frequency of interaction triggers is positively correlated with narrative logic feedback, suggesting a matching relationship between behavioral activation and information presentation. The path stability improved from 0.62 to 0.81, indicating that the audience maintains good behavioral continuity within the narrative flow, with information node switching and operational rhythm being quite consistent.

B. EMOTION AND PARTICIPATION

The emotion and engagement results integrate facial recognition, psychological questionnaires, and synchronized behavioral data, including the audience's emotions and engagement throughout the narrative process. The emotion recognition algorithm identifies the emotional intensity value from the time series of facial expression muscle movements to match behavioral trigger data. After data standardization and weighting, the mean emotional engagement increased from 3.21 before the experiment to 4.14, an improvement of 29%. This indicates that IxD's narrative optimization method contributes to the depth of experience. Specific data are shown in Table 2.

TABLE 2. Statistics on Emotion and Engagement Data

Indicator Categories	Pre-experiment mean	Post-experiment mean	Increase ratio	Data source dimensions
Emotional commitment rating	3.21	4.14	29%	Questionnaire and recognition fusion data
Positive feedback rate (%)	64.1	82.5	22.3%	Audience behavior response
Emotional synchronization coefficient	0.63	0.87	38.1%	Facial recognition data
Emotional stability index	0.71	0.85	19.7%	Mood fluctuation mapping
Immersion duration (seconds)	228	294	28.9%	Joint recording of emotional and behavioral flows

Similar to the behavioral flow, the peak concentration of audience emotional responses at high-frequency interaction nodes increased to 0.87, which matches the rhythm of the exhibition narrative nodes; the average correlation coefficient between the questionnaire results and the system identification results was 0.79, indicating a high degree of consistency between subjective emotional evaluation and objective identification results; the emotional stability index increased by 19.7%, and the average immersion time of the audience during the interaction process reached 294 seconds, indicating more sustained cognitive and emotional

investment.

C. MODEL APPLICABILITY ANALYSIS

The model achieves adaptive scheduling in narrative expression by coupling behavioral and informational flows, establishing information feedback relationships between audience actions and narrative nodes. Interactive variables exhibit a certain time lag, with information flow delays within 0.42 seconds. Table 3 presents the applicability analysis of the interaction design model:

TABLE 3. Applicability Analysis of Interaction Design Models

Analysis indicators	Pre-experiment mean	Post-experiment mean	Change ratio	Data source dimensions
Information flow response latency (seconds)	0.73	0.42	-42.5%	System operation log
Participation Depth Index	0.58	0.79	36.2%	Behavioral monitoring data
Emotional synchronization rate	0.67	0.86	28.4%	Facial recognition system
Immersive Experience Index	0.71	0.83	16.9%	Questionnaire and system integration
Behavior-emotion correlation coefficient	0.64	0.81	26.5%	Comprehensive data model

The model enhances audience engagement by using a dynamic interaction mechanism to create a synchronous growth effect between behavioral paths and narrative logic. The audience engagement depth index rose from 0.58 to 0.79, indicating that behavioral activation and emotional feedback form a mutually reinforcing mechanism.

The system maintains a high emotional synchronization rate during high-frequency triggering, and the narrative immersion index remains stable above 0.83 in all three rounds of testing, demonstrating that the IxD-based exhibition system has a strong ability to self-regulate the perception rhythm. The correlation coefficient between behavioral data and emotional data is 0.81, indicating strong adaptability at the data fusion level, which is consistent with the narrative feedback logic structure proposed in the study.

D. LIMITATIONS AND OPTIMIZATION DIRECTIONS

The study suffers from shortcomings in data structure and model training accuracy. While the audience sample covers different groups, its temporal and spatial distribution

density is low, resulting in poor data representativeness. The concentrated distribution of behavioral samples in high-frequency interaction segments causes a shift in the emotion value fitting function, amplifying the emotional responses of some narrative nodes and affecting the model's generalization performance. Data weight shifts lead to a mismatch between behavioral and information flows, resulting in local distortions in complex narrative paths. Improvements should focus on expanding the sample range, increasing cross-scene collection batches, and fusing data from multiple time periods to enhance the spatiotemporal continuity of dynamic stream data. The emotion analysis algorithm suffers from overfitting in recognition accuracy and emotion boundary segmentation, leading to error accumulation in facial expression micro-movements and emotion gradient identification. This causes lag in decoding some emotion stream signal features, affecting the stability of real-time feedback. Improvements should focus on multimodal data training, utilizing semantic layer feature weight allocation and temporal convolutional structures to improve the reso-

lution and timeliness of emotion signals, enabling continuous response in high-frequency information switching and enhancing the system's robustness and feedback balance in narrative adaptation and experience scheduling.

V. CONCLUSION

A. KEY FINDINGS OF THE STUDY

The IxD framework plays a stable regulatory role in the linkage between information flow, behavior flow, and emotional flow in the exhibition narrative system. The audience's behavior path is more continuous under the dynamic narrative structure, and the frequency of interaction triggers and emotional investment show a linear growth trend, indicating that the introduction of the interaction mechanism enhances the narrative expressiveness.

The model achieves adaptive control of content rhythm through data feedback, enabling the audience to form a coordinated response between information reception and psychological immersion. The interactive design framework promotes the construction of a multi-dimensional dissemination structure of content logic at the narrative expression level and gives the audience a higher depth of participation.

B. THEORETICAL AND PRACTICAL VALUE

At the theoretical level, the dynamic mapping between narrative logic and audience experience is incorporated into the research path of information interaction. At the practical level, algorithmic parameters and spatial behavior monitoring methods are used to promote the transformation of exhibitions from static content display to dynamic interactive systems, forming a quantifiable narrative practice model.

C. FUTURE RESEARCH PROSPECTS

In the future, the focus will be on the integration of virtual reality and multimodal sensory data. This will involve expanding the immersion of narrative experiences through spatial recognition and physiological signals, optimizing the combination of visual, auditory, tactile, and emotional signals in the system, and improving the audience's actions and continuity in virtual spaces. The aim is to construct high-dimensional narrative expressions, mutually incentivizing virtual scenes and real-world behaviors, and providing evolutionary technologies for interactive storytelling.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Ethics Committee of Shanghai Art & Design Academy, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

AUTHOR CONTRIBUTIONS

Yingli Xiao designed, collected and analyzed the data, and drafted the manuscript. Yingli Xiao conducted the study, critically revised the manuscript for important intellectual

content, and gave final approval of the version to be published. Yingli Xiao participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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