Research on the Design of a Balance Between Education and Entertainment in Study-Travel Products Based on AHP-FCE

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ABSTRACT

Addressing the challenge of balancing educational and recreational elements in the design of educational travel products, this study proposes a quantitative design method based on the Analytic Hierarchy Process (AHP) combined with Fuzzy Comprehensive Evaluation (FCE). Through user research, emotional needs are identified, and the Kawakita Jiro (KJ) method is employed for demand clustering to establish a mapping relationship between emotional vocabulary and design elements. A hierarchical analysis model is then constructed to determine the weights of these elements. Using the Maritime Silk Road culture case study, the Fuzzy Comprehensive Evaluation (FCE) method is applied to comprehensively evaluate the design proposals, validating the effectiveness of the "culture as the core, interaction as the medium, and practicality as the foundation" design strategy. The developed research-based educational cultural board game prototype achieves an organic integration of educational functions and entertainment experiences. The research findings not only provide quantifiable decision-making criteria for the balanced design of cultural and creative products, but also expand the application paradigm of emotional engineering in the cultural and creative field, while offering practical references for the innovative transformation of traditional culture.

Keywords: *Game chess, Research-based Educational Cultural Products, Kansei Engineering(KE), Kawakita Jiro(KJ), Analytic Hierarchy Process(AHP), Fuzzy Comprehensive Evaluation(FCE).*

1. INTRODUCTION

With the "14th Five-Year Plan" promoting cultural and educational development, the market for research-based educational cultural products has expanded rapidly [1]. To address common issues like weak interactivity and short knowledge retention, cultural and creative research chess has emerged as a key product category. While such board games enhance engagement and deepen learning, most existing studies focus on "cultural IP + board game" transformation, with limited research on balancing education and entertainment. Therefore, this paper investigates how to integrate educational and entertaining elements in research-based educational board games from a user-needs perspective.

2. CURRENT STATUS OF RESEARCH-BASED EDUCATIONAL BOARD GAMES

Research-based educational cultural board game (hereafter referred to as "Educational Board Games") serve as a primary medium for cultural and creative products, integrating cultural themes, creative design, educational functions, and entertainment value. Currently, the market for Educational Board Games exhibits a trend of "robust demand coupled with supply imbalance." Existing products often face a polarized dilemma: either overemphasizing educational content at the expense of gameplay enjoyment, or prioritizing superficial entertainment while diminishing knowledge retention effectiveness. The market urgently requires a scientific methodology to resolve this educational-entertainment imbalance

and unlock the industrial potential of cultural and creative research-based board games.

Employing the SET model, this study evaluates the necessity and feasibility of balancing education and entertainment in research-based board games. Findings indicate: Socially, such games promote holistic cognitive development and cultural heritage by cultivating thinking skills. Economically, growing demand for quality, personalized education drives interest in products that combine learning with engagement. Technologically, innovations like virtual reality provide new ways to balance educational and entertainment value, with immersive experiences deepening children's interaction with content [2]. Supported by policy and technology, these dimensions highlight key opportunities for developing board games that successfully integrate educational and entertaining features.

3. RESEARCH METHODS

Research-based education underpins cultural education. As a key educational tool that blends learning with engagement, the Educational Board Games transforms historical and cultural knowledge into an interactive rule system. Its design applies "gamification thinking" to reshape how knowledge is conveyed—using rules to deepen interaction rather than superficially adding content, thereby improving the appeal and cultural impact of research activities. This reduces the monotony of traditional educational cultural products and strengthens cultural memory through participation. However, overemphasizing entertainment may oversimplify cultural content, while too strong a focus on education can reduce engagement. To address this, the study integrates affective engineering theory, combining the KJ method, analytic hierarchy process (AHP), and fuzzy comprehensive evaluation to establish a systematic design pathway.

Sensory Engineering, proposed by Japanese scholar Mitsuo Nagamachi, quantifies users' sensory perceptions to guide product design [3], while Li Jing et al. [4] used it to innovate Ji-yu roof tile designs through cultural interpretation. This method helps precisely identify emotional needs of users in educational board games design.

The KJ Method (Affinity Diagram), developed by Jiro Kawakita, extracts patterns from qualitative data. Tianlong Xie [5] used it to identify 18 user needs for library cultural products; Li Lin et al. [6] adopted it to categorize needs and develop user personas. Its hierarchical model can classify user requirements for educational board games, supporting subsequent AHP modeling.

The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty, quantifies qualitative factors in complex decisions. Wang Luyao et al. [7] built an AHP-based evaluation system for museum cultural design; Zhou Yi et al. [8] constructed an evaluation system for red cultural products. AHP can classify functional indicators and weight design elements for educational board games, guiding design priorities and fuzzy evaluation.

Fuzzy Comprehensive Evaluation (FCE) uses membership functions to quantify qualitative indicators, avoiding bias from forced quantification. Huang Jiani et al. [9] applied FCE to design social-intervention tools for children with autism; [10] used it to assess design proposals. FCE is suitable for screening optimal solutions and evaluating the overall efficacy of educational board games designs.

In summary, existing research on cultural and creative educational design offers important groundwork for this study. However, academic inquiry into the specific domain of cultural and educational board games is still nascent. Despite ongoing policy support that promotes industry development, product design often fails to keep pace with market trends, mainly due to the persistent challenge of balancing educational and entertainment value. This misalignment restricts the synergy between cultural transmission and user experience. Thus, introducing a systematic quantitative methodology is essential for addressing this gap.

4. RESEARCH AND DEVELOPMENT PROCESS FOR MARITIME SILK ROAD RESEARCH-BASED EDUCATIONAL BOARD GAMES

4.1 Research Process

Driven by consumption upgrades, users of educational board games sets exhibit increasingly diverse and personalized demands. This study employs Maritime Silk Road culture as its empirical framework, following this research process: (1) Employing affective ergonomics to extract affective imagery vocabulary from target users regarding educational board games samples; (2) Systematically organizing and integrating the

three-tiered demand levels of educational board games through the KJ method; (3) Constructing a judgment matrix using the Analytic Hierarchy Process (AHP) to calculate the weight values of each design element; (4) Based on prior findings, conduct design practice for a Maritime Silk Road-themed cultural and educational board game; (5) Validate the feasibility of the design proposal using the Fuzzy Comprehensive Evaluation Method, demonstrating the practical value of theoretical outcomes through evaluation results. This research establishes a quantitative-driven design process, providing a methodological paradigm for balancing the educational and recreational attributes of research-based educational board games. Determining Emotional Vocabulary

Employing a systematic sampling and screening methodology, 102 initial samples of cultural and creative board games were collected from mainstream social media and e-commerce platforms using Python web scraping technology. Rigorous screening criteria were established: first, eliminating products with over 85% visual similarity as derivatives, and excluding variants with more than 70% gameplay overlap; Subsequently, a three-dimensional classification system was constructed based on educational functionality, entertainment experience, and dynamic structure, employing stratified proportional sampling to ensure category balance; Ultimately, 30 representative samples with significant differentiation were selected ("Figure 1"), meeting preset criteria for thematic uniqueness, gameplay innovation, and market representativeness. This sample set provides a reliable data foundation for subsequent quantifiable affective engineering analysis. The entire screening process strictly adhered to experimental design protocols, ensuring scientific rigor and reproducibility of research outcomes.

Figure 1 Sample of educational board games for research and study.

Using Python web scraping technology, the researchers systematically collected 4,256 user review data points from academic paper databases, specialized websites, industry monographs, and e-commerce platforms. Leveraging natural language processing (NLP) techniques, we employed text segmentation tools for data processing, constructed a stopword list to filter irrelevant vocabulary, and utilized an NLP processor to perform word frequency statistics and high-frequency feature word selection. Through supplementary literature review, 32 monographs and 68 academic papers were consulted to preliminarily compile 82 representative emotional imagery terms. Subsequently, a review panel comprising 5 industry experts and 3 senior designers was convened to conduct multiple rounds of screening. Strictly adhering to the "secondary nature" principle of the semantic difference method, 10 pairs of emotional vocabulary with significant distinctiveness were ultimately identified ("Table 1"). The entire extraction process documented all data processing steps in full, rigorously following the emotional engineering research paradigm to ensure the verifiability and scientific validity of the findings.

Table 1. Representative KE Pairs

Serial Number	Semantic Pair	Serial Number	Semantic Pair
1	Cultural - Superficial	6	Strategic - Disorderly
2	Fun - Boring	7	Interactive - Independent
3	Exquisite - Spartan	8	Immersed - Detached
4	Portable - Complex	9	Achievement-Setback
5	Intelligent - Clumsy	10	Three-dimensional - Two-dimensional

4.2 Analysis of Target User Requirements Based on the KJ Method

Based on semi-structured interviews and the KJ method, a hierarchical model of user needs for educational board games study tours was systematically constructed. Raw data from students and parents were collected through interviews [11], and after three-stage qualitative analysis using the KJ method, a demand system comprising three secondary dimensions and ten tertiary indicators was established: content and cognitive needs, interaction and entertainment needs, and design and form needs. A "needs-to-functions" conversion matrix, rigorously constructed following qualitative norms, provides the theoretical framework for subsequent AHP analysis. This enables the transformation of users' intuitive perceptions into quantifiable design parameters [12]. Implementation of Judgment Matrix Construction and Weight Calculation Based on the Analytic Hierarchy Process

Through the analytic hierarchy process (AHP) model, combined with the demand classification for the Maritime Silk Road Cultural Creative Research and Study Board Game design identified in the earlier KJ method, the primary and secondary demands are respectively mapped to the goal layer, criterion layer, and indicator layer of the AHP model. This yields the AHP model for the Maritime Silk Road Cultural Creative Research and Study Board Game design, as shown in "Figure 2".

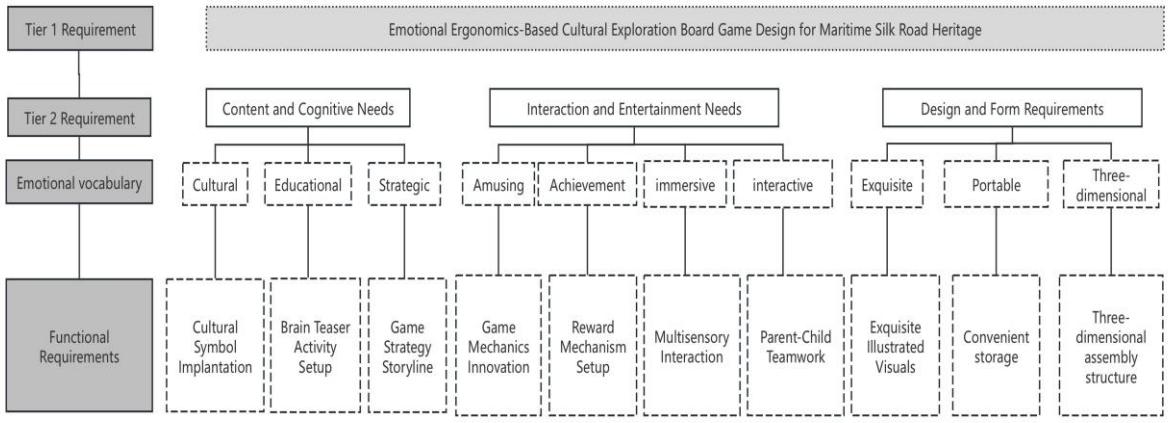

Figure 2 Hierarchical Analysis model for the design of Maritime Silk Road research-based educational board games.

Subsequently, 15 experts in the design field were invited to evaluate the requirements for the educational board games. This group included 3 professors from the Industrial Design Department, 4 education specialists, 5 visual communication designers, and 3 product designers. Experts used the Saaty scale (1-9) to conduct pairwise comparisons of elements within the same layer, scoring them according to the criteria in "Table 2". They then discussed the scoring results and reached a consensus. For each comparison matrix, the obtained metric data underwent normalization processing, and the weight values for the judgment matrices were calculated, as shown in "Table 4" "Table 5" and "Table 6".

Following the calculation of consistency test results, the CR values for all judgment matrices were less than 0.1, validating the reliability of the demand factors.

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(Aw)i}{nwi} \quad (1)$$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (2) \qquad CR = \frac{CI}{RI} \quad (3)$$

Table 2. Rating scale

Criteria for Judgment	Definition	Explanation
1	Equally important	Both factors contribute equally to the objective.
3	Slightly important	One factor is slightly more important than another.
5	Significantly important	One factor is clearly more important than another.
7	particularly important	One factor is significantly more important than another.
9	Extremely important	One factor is of paramount importance compared to another.
2，4，6，8	Median	Used as a compromise value for situations falling between the aforementioned judgment criteria.

Table 3. Consistency test table

n	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 4. Weights of the layer A judgment matrix

A	B1	B2	B3	Weighting	CR
B1	1	3	5	0.619	0.075
B2	1/3	1	4	0.284	
B3	1/5	1/4	1	0.097	

Calculations indicate B1 > B2 > B3, with a CR value of 0.075 < 0.1, confirming the validity of this data. This demonstrates that content and cognitive dimensions are paramount at this level, followed by interaction and entertainment dimensions, and design and form dimensions.

Table 5. Weights of the B-layer judgment matrix

B1	C1	C2	C3	Weighting	CR
C1	1	1/2	5	0.366	0.082
C2	2	1	4	0.532	
C3	1/5	1/4	1	0.102	

B2	C4	C5	C6	C7	Weighting	CR
C4	1	1/5	1/3	1/6	0.060	0.081
C5	5	1	3	1/4	0.248	
C6	3	1/3	1	1/5	0.213	
C7	6	4	5	1	0.569	

B3	C8	C9	C10	Weighting	CR
C8	1	1/5	1/2	0.118	0.033
C9	5	1	3	0.637	
C10	2	1/3	1	0.245	

Table 6. Weights of the global judgment matrix for layer C

Sub-principle	Description	C-layer weight	Global Weight	Ranking	Explanation
C2	Brain Teaser Activity Setup	0.532	0.329	1	B1 Core, emphasizing intellectual development
C1	Cultural Symbol Implantation	0.366	0.227	2	Vehicle of Cultural Significance

Sub-principle	Description	C-layer weight	Global Weight	Ranking	Explanation
C7	Parent-Child Teamwork	0.569	0.162	3	B2 Core: Promoting Family Interaction
C5	Reward Mechanism Setup	0.248	0.070	4	Encourage sustained participation
C3	Game Strategy Storyline	0.102	0.063	5	Supplementary educational
C9	Convenient storage	0.637	0.062	6	B3 Core, highly practical
C6	Multisensory Interaction	0.213	0.061	7	Enhance immersion
C10	Three-dimensional assembly structure	0.245	0.024	8	Usability Design
C4	Game Mechanics Innovation	0.060	0.017	9	Innovation is secondary
C8	Exquisite Illustrated Visuals	0.118	0.011	10	Least visually appealing

5. CULTURAL HERITAGE BOARD GAME DESIGN PRACTICE FOR MARITIME SILK ROAD STUDIES

5.1 Strategy Transformation for Research-Based Educational Board Game Design Based on the Analytic Hierarchy Process

Based on the weight analysis results (Content and Cognition B1: 61.9%, Interaction and Entertainment B2: 28.4%, Design and Form B3: 9.7%), this study proposes a design strategy centered on “culture as the core, interaction as the medium, and utility as the foundation”, allocating R&D resources accordingly.

Specifically, 61.9% of resources are concentrated on the content cognition dimension, prioritizing enhancements to cognitive engagement (C2) and cultural symbol integration (C1) to strengthen the product’s educational functionality. 28.4% of resources are allocated to the interactive entertainment dimension, emphasizing parent-child teamwork (C7) as a core differentiator. Only 9.7% of resources were allocated to the design form dimension, prioritizing practical functions like easy storage (C9) while minimizing investment in low-priority visual and mechanism elements. This strategy aims to precisely meet target users’ integrated needs for “light learning, heavy interaction, and simple storage” through a dual-core drive of “cultural cognition + parent-child interaction”.(“Figure 3”)

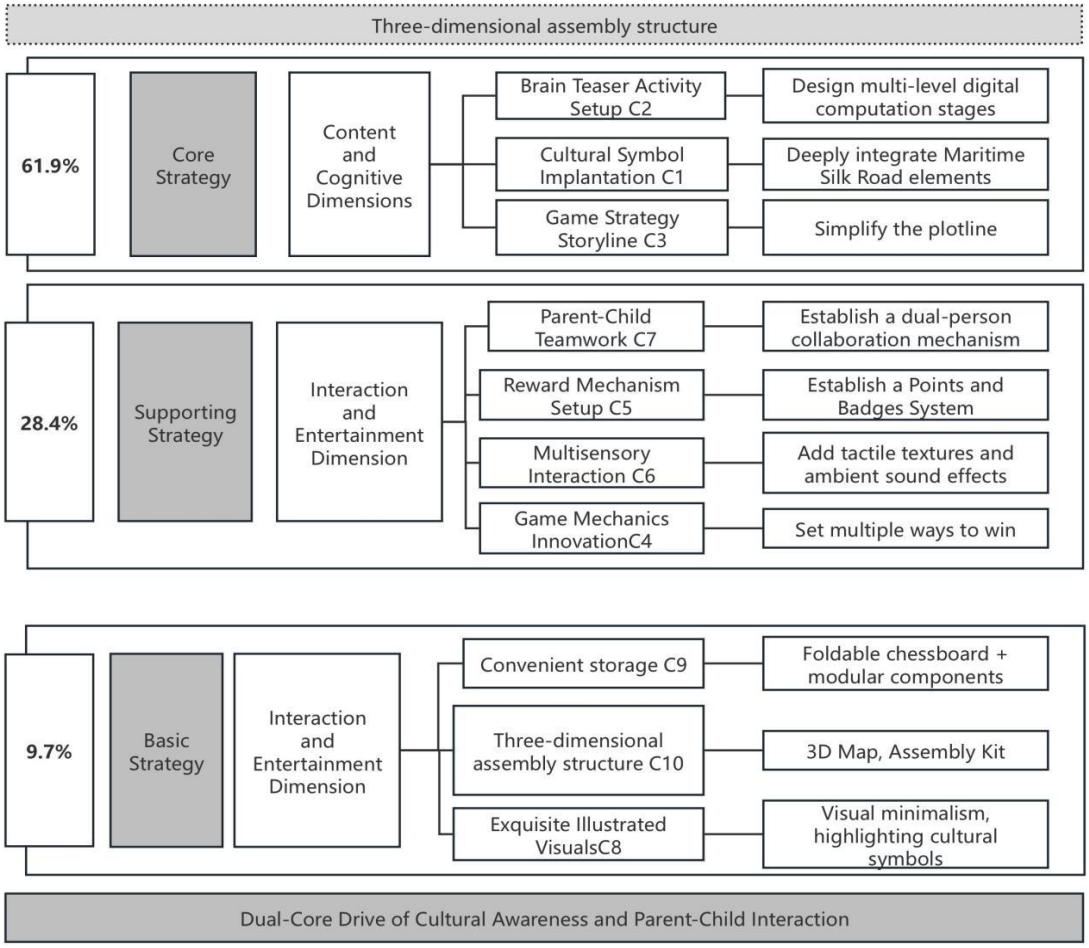

Figure 3 Design strategy for maritime silk road research-based educational board games.

5.2 Maritime Silk Road Research-based Educational Board Games Design Practice

In the design practice, guided by the dual-core strategy of "cultural cognition and parent-child interaction," this study developed the educational board game Maritime Silk Road: Afu's Treasure Hunt (Figure 4). The design integrates cultural symbols of the Maritime Silk Road into a multidimensional educational framework. For example, the character system introduces skill mechanics based on historical prototypes: the Zheng He character possesses unique abilities such as "Seven Voyages to the Western Seas" and "Protection of the Sea God," allowing cross-grid movement and event exemption.The cognitive reinforcement module embeds math problems in trade-event cards to develop children's calculation skills with parental assistance. Relic events trigger simplified history quizzes. A two-player captain-crew collaboration mechanism requires players to jointly complete cultural decoding tasks, such as assembling a Kaiyuan Temple mural puzzle. The incentive system awards a "Maritime Silk Road Cultural Ambassador" badge after ten consecutive correct answers, creating an achievement-driven loop. Multimodal interaction combines AR cultural-relic education with tactile material cards (e.g., silk and spices) to enhance sensory immersion.Spatially, a three-layer modular board—comprising the Maritime Silk Road Foundations, Commercial Hub Dynamics, and Maritime Silk Road Renaissance—forms a study-game route that embodies "dialogue between past and present, uniting knowledge with action." Quantitative analysis shows that the educational dimension dominates the game's design, while entertainment is strategically integrated through collaborative mechanisms and reward systems, ultimately achieving a dynamic balance between education and engagement.

Figure 4 Maritime Silk Road Cultural Study Game Board "Journey of the Sea-Bark Ship: Afu's Gold Rush Adventure".

5.3 Design Evaluation Based on FCE

Compared to using fuzzy comprehensive evaluation alone, combining it with AHP yields more objective weight values. When evaluating the scheme using FCE and conducting consistency tests, the CR values for all indicators were less than 0.1, indicating that each demand factor possesses a certain degree of reliability [13]. The specific process for the fuzzy evaluation of the Maritime Silk Road educational board gamesdesign scheme is as follows ("Table 7"):

Table 7. Sub-criterion layer comprehensive weight

Guideline Layer	Guideline Layer Weight	Sub-principle Level	Sub-criterion Layer Weight	Sub-principle Level Comprehensive Weighting	Sorting
Content and Cognitive DimensionsB1	0.619	Cultural Symbols Embedded in C1	0.366	0.227	2
		Brain Teaser Section C2	0.532	0.329	1
		Game Strategy Storyline C3	0.102	0.063	5
Interaction and Entertainment Dimension B2	0.284	Game Mechanics Innovation C4	0.060	0.017	9
		Reward Mechanism Configuration C5	0.248	0.070	4
		Multi-sensory Interaction C6	0.213	0.061	7
		Parent-Child Teamwork C7	0.569	0.162	3
Design and Form Dimension B3	0.097	Exquisite Illustration Visual C8	0.118	0.011	10
		Convenient Storage C9	0.637	0.062	6
		Three-Dimensional Assembly Structure C10	0.245	0.024	8

This study constructed a multi-level evaluation indicator system: First, an indicator set was established based on the reviews of 10 experts; second, a factor set was constructed using indicator elements determined by the Analytic Hierarchy Process (AHP). This system comprises three primary criteria indicators O = (u1, u2, u3), corresponding to the dimensions of content cognition, interactive entertainment, and design form, respectively, along with ten secondary sub-criteria indicators (ui = (uij) (i, j = 1, 2, 3, 4, 5)).

The evaluation indicators for the Maritime Silk Road Research-based Educational Board Games design scheme were defined as V = (V1, V2, V3, V4) = (Excellent, Good, Passing, Failing), with the comment vector specified as β = (90, 80, 60, 50)^T.

Based on "Table 7" data, the decision matrix and weight vectors for each level of the Maritime Silk Road Cultural Theme Study Board Game Design Evaluation System can be calculated. Specifically: - The weight vector for criteria-level evaluation indicators is W = (0.619, 0.284, 0.097); The weight vectors for sub-criteria indicators are W1 = (0.366, 0.532, 0.102), W2 = (0.060, 0.248, 0.213), and W3 = (0.569, 0.118, 0.637, 0.245).

The researchers construct the fuzzy comprehensive evaluation matrix. The evaluation matrices for the game board scheme under the sub-criteria layers of the Content and Perception Dimension, Interaction and Entertainment Dimension, and Design and Form Dimension are denoted as Z1, Z2, and Z3, respectively.

$$Z_1 = \begin{bmatrix} 0.4 & 0.5 & 0.1 & 0 \\ 0.5 & 0.4 & 0.1 & 0 \\ 0.3 & 0.4 & 0.3 & 0 \end{bmatrix} \quad (4)$$

$$Z_2 = \begin{bmatrix} 0.2 & 0.5 & 0.3 & 0 \\ 0.4 & 0.4 & 0.2 & 0 \\ 0.3 & 0.5 & 0.2 & 0 \\ 0.5 & 0.4 & 0.1 & 0 \end{bmatrix} \quad (5)$$

$$Z_3 = \begin{bmatrix} 0.3 & 0.4 & 0.3 & 0 \\ 0.4 & 0.5 & 0.1 & 0 \\ 0.3 & 0.5 & 0.2 & 0 \end{bmatrix} \quad (6)$$

By combining the weights W1, W2, and W3 derived from the analytic hierarchy process with the fuzzy judgment matrices Z1, Z2, and Z3, the fuzzy comprehensive evaluation result vector corresponding to the game chess scheme can be obtained:

$$M_1 = \mathbf{W}_1 \times \mathbf{Z}_1 = (0.443, 0.4366, 0.1204, 0) \quad (7)$$

$$M_2 = \mathbf{W}_2 \times \mathbf{Z}_2 = (0.4596, 0.4633, 0.1671, 0) \quad (8)$$

$$M_3 = \mathbf{W}_3 \times \mathbf{Z}_3 = (0.3637, 0.4482, 0.1481, 0) \quad (9)$$

The researchers reconstruct the matrix using the evaluation result vector described above:

$$\mathbf{M} = \begin{bmatrix} \mathbf{M}_1 \\ \mathbf{M}_2 \\ \mathbf{M}_3 \end{bmatrix} = \begin{bmatrix} 0.443 & 0.4366 & 0.12.04 & 0 \\ 0.4596 & 0.4633 & 0.1671 & 0 \\ 0.3637 & 0.4482 & 0.1481 & 0 \end{bmatrix} \quad (10)$$

The fuzzy comprehensive evaluation results for the design scheme of the Maritime Silk Road Cultural Research Game Board are obtained by performing weighted summation on matrix M using weight vector W. The comprehensive evaluation vector is:

$$\mathbf{WxM} = (0.44, 0.4493, 0.1364, 0) \quad (11)$$

The percentage-based scoring results for the Maritime Silk Road Cultural Creative Research and Study Chess Program are as follows:

$$\mathbf{P} = \mathbf{W} \times \boldsymbol{\beta} = 83.728 > 80 \quad (12)$$

The Maritime Silk Road Research-based Educational Board Games Program achieved a comprehensive score of 83.728 points. To validate the conclusion's validity, three competing products from the bestseller lists of similar cultural research games sets on Taobao and JD.com were selected. Calculated using the same methodology, Competitor A scored 74.8 points, Competitor B scored 71.2 points, and Competitor C scored 77.6 points. Applying a weighted average algorithm yielded a weighted benchmark score of 74.56. Compared to the benchmark score of 74.56 for mainstream products on the market, this proposal scored 9.1% higher. The proposal meets design expectations and demonstrates feasibility for promotion.

Table 8. Benchmark scores for mainstream commercial products

Competitor	Competitor A	Competitor B	Competitor C
Solution			
Overall Score	74.8	71.2	77.6
Weighted Base Score	74.56		

6. CONCLUSION

This paper proposes a user-centered design methodology for research-based cultural board games. It applies the KJ method to define user needs, AHP to quantify their weights, and FCE to evaluate prototypes. This provides a quantifiable framework for balancing education and

entertainment, reducing the tension between learning and engagement. The Maritime Silk Road design case extends affective engineering theory in cultural product design and offers a practical reference. Future work will refine the methodology and explore further cultural integration strategies.

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