A Hybrid Evaluation Framework for Children's Study Desks: Combining AHP–TOPSIS and Online Review Analysis

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Designing study desks that align with children's developmental characteristics and learning needs requires a comprehensive and objective evaluation framework. This study proposes a hybrid evaluation framework that integrates the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) with online review analysis, aiming to bridge expert judgment and real-world user perception. The evaluation system was constructed through literature review, user interviews, and expert consultation, covering five primary criteria—Functionality, Structure, Material, Appearance, and Personalization—and seventeen subcriteria. Using AHP, indicator weights were derived, and representative study desk products were assessed through the AHP–TOPSIS model. To validate the model, online user reviews were collected and analyzed through sentiment analysis, enabling a comparison between calculated rankings and market acceptance. Results showed that Functionality and Structure were the dominant determinants, with adjustable height, operational safety, and environmental safety as the most influential factors. Consistency between AHP–TOPSIS rankings and online sentiment confirmed the framework's reliability. Review analysis also highlighted latent dimensions, such as ease of installation and service experience, providing insights for refining product evaluation. This study offers a scientific and market-responsive approach to children's furniture design assessment.

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INTRODUCTION

Education has long been recognized as a strategic foundation for national development, shaping future competitiveness and social sustainability (Goczek *et al.* 2021). Recent educational reforms have shifted attention from basic access toward improving the quality and effectiveness of learning (Zhang *et al.* 2025). These changes have been accompanied by increasing household investment in children's development. As family structures and consumption patterns evolve, children exert growing influence on household decisions related to learning environments, contributing to the expansion of the home study furniture market (Lin 2018).

Childhood is a critical period for cognitive and noncognitive development (Liu 2020). Meanwhile, global education systems have undergone rapid transformation, particularly after COVID-19, with home-based learning becoming increasingly common (Iivari *et al.* 2020). Consequently, the home learning environment—an important extension of school settings—has gained growing attention for its scientific, adaptive, and health-oriented design (Brachtl *et al.* 2023). This study focuses on primary-school children aged 6 to 12 years, whose rapid physical growth and developing study habits require adaptive and ergonomically appropriate furniture. Among its key components, the study desk serves as the primary interface supporting children's learning behaviors. Unlike school classroom furniture, these desks are mainly used in home settings, where parents rather than teachers are typically the primary decision-makers in product selection and often guide children's study routines. Details related to the furniture affect posture, concentration, and musculoskeletal health, and they contribute to creating a conducive learning atmosphere (Oyewole *et al.* 2010). Compared with general household furniture, children's study desks require distinctive ergonomic, safety, and functional considerations that accommodate rapid physical growth and diverse household expectations.

Existing research has primarily focused on school furniture. Numerous studies have examined the ergonomic suitability of classroom desks and chairs (Saarni *et al.* 2007; Carneiro *et al.* 2017) or evaluated innovative activity-based furniture such as standing desks, cycling desks, and stability-ball setups (Dinkelspiel Ekman *et al.* 2025). In contrast, research on home study desks remains limited. Miao *et al.* (2024) analyzed consumer preferences using an AHP–QCA model, Hao and Wu (2025) proposed design strategies for intelligent study desks, and Xiao (2025) developed an indicator system based on common problems observed during children's writing and reading activities. While informative, these studies lack a comprehensive evaluation framework integrating ergonomics, developmental needs, and market feedback. Moreover, few have validated expert-based assessments against real user data, reducing their practical applicability.

To address these gaps, this study organized the evaluation of children's study desks around five primary design-related dimensions, namely functionality, structural characteristics, material-related performance, visual and aesthetic qualities, and personalization features. These dimensions, derived from both user investigations and expert consultation, form the hierarchical criteria structure underlying the analysis. Based on this structured framework, an integrated AHP–TOPSIS approach is employed to quantify and weight these criteria. The model is further validated using real-world online review data, forming a closed-loop assessment process. This approach aims to bridge the disconnect between design evaluation and actual market acceptance.

EXPERIMENTAL

Method

AHP method

The Analytic Hierarchy Process (AHP), proposed by T. L. Saaty in the 1970s, is a decision-making method that uses pairwise comparisons and expert judgments to derive priority scales (Saaty 1990). Designed to address complex decision problems, AHP constructs a multi-level analytical structure that integrates both qualitative insights and quantitative assessments, thereby improving the scientific rigor and logical consistency of decision-making (Wang and Zhao 2024; Xie *et al.* 2024). Owing to its clarity and effectiveness, AHP has been widely applied across fields such as management, engineering, and manufacturing. For example, Zhao and Xu (2023) employed AHP to evaluate design factors for wooden storage cabinets for children, while Chen and Sun (2023) used AHP to construct an indicator system based on user requirements for laminated wood-based panels. Fan and Wang (2025) further applied AHP to develop a sustainable gift-packaging evaluation model, providing a structured method for environmentally conscious product development. In this study, AHP was applied in three main steps:

(1) Constructing a judgment matrix through pairwise comparisons using a 1 to 9 scale (Table 1);

$$A = \begin{bmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{n1} & \cdots & b_{nn} \end{bmatrix} \tag{1}$$

Table 1. The Scale of Judgment Matrix

Scale	Materiality Rating	Meaning of Materiality
1	Equally Importance	Indicator A and Indicator B are equally important
3	Slightly Important	Indicator A is slightly more important than Indicator B
5	Clearly Important	Indicator A is more important than Indicator B
7	Strongly Important	Indicator A is significantly more important than Indicator B
9	Absolutely Important	Indicator A is definitely more important than Indicator B
* When comparing indicator B to indicator A, the weight should be the inverse of the scale above.		

(2) Calculating indicator weights using the geometric mean method, with the formula given below, where a_i denotes the geometric mean of the scale products for each row;

$$W_i = \frac{a_i}{\sum_{i=1}^{m} a_i} \tag{2}$$

(3) Performing a consistency check, where CI is the consistency index and RI the random consistency index. CR ⩽ 0.1 indicates successful consistency; otherwise, the judgment matrix must be revised and recalculated.

$$CR = \frac{CI}{RI} \tag{3}$$

TOPSIS method

TOPSIS is a multi-objective decision-making method originally developed by Yoon and Hwang (1995). By defining positive and negative ideal solutions, TOPSIS evaluates each alternative based on its distance from the optimal and worst performance points (Pei 2015). Options closer to the positive ideal and farther from the negative ideal are considered superior. Because indicator weights are required to establish the ideal solutions, TOPSIS is often combined with weighting techniques such as entropy weighting for residential building evaluation (Chen and An 2024) and the CRITIC method for home product performance assessment (Yu *et al.* 2024). Its simplicity, computational efficiency, and limited reliance on subjective judgment make TOPSIS well-suited for applied product evaluation. In this study, it was applied in two main steps:

(1) Constructing a normalized weighted decision matrix based on AHP-derived weights. Equation 4 is the normalized matrix, X is the number of solutions, and Z is the weighted standard decision matrix.

$$Y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{4}$$

$$z_{ij} = \omega_i Y_{ij} \tag{5}$$

(2) Calculating the relative convergence T_i of each product to the ideal solution to establish the ranking order. D^+ and D^- are the positive and negative ideal solutions, with S^+ and S^- representing Euclidean distances to them.

$$D^+ = max\{z_j, z_{2j}, \cdots, z_{nj}\} (j = 1,2, \cdots, m) \tag{6}$$

$$D^- = max\{z_j, z_{2j}, \cdots, z_{nj}\} (j = 1,2, \cdots, m) \tag{7}$$

$$T_i = \frac{S_i^-}{s_i^+ + S_i^-}, (\mathrm{i} = 1,2, \cdots, m) \tag{8}$$

Design evaluation flowchart

This study employed an AHP–TOPSIS–based evaluation framework, as shown in Fig. 1. First, user requirements were identified through literature review and expert consultation. Representative products were then selected, and the AHP method was used to establish the hierarchical evaluation system and determine indicator weights. Based on these weights, TOPSIS was applied to construct the weighted decision matrix, compute ideal solutions, and derive product rankings. Finally, online reviews of the selected products were collected using the Amingchacha data tool, filtered, and analyzed for sentiment to obtain an acceptance ranking, which was then compared with the AHP–TOPSIS results for validation.

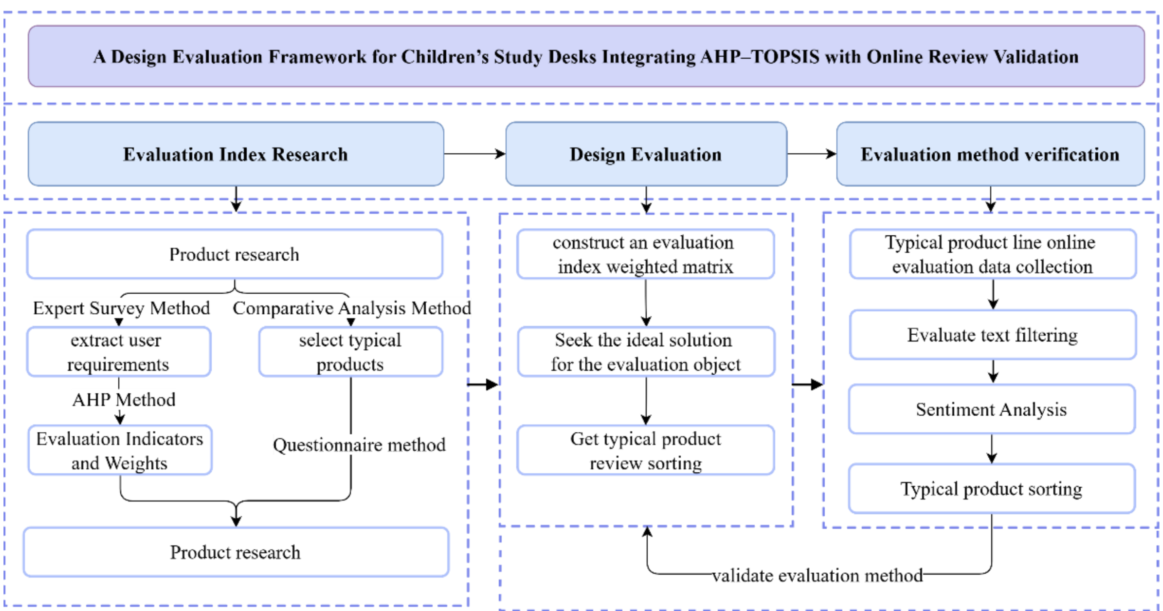

Fig. 1. Design evaluation flowchart

Case Study

Evaluation indicators study

A comprehensive review of existing literature on children's study desks was conducted, and relevant commercial products were examined. In addition, interviews were carried out with two user groups—children and their parents—to collect textual data from their discussions. These data were processed by tagging each sentence to capture the essential needs expressed by the respondents, ensuring consistency with their original intentions and adhering to localization principles. Through this structured process of textual data analysis, a comprehensive evaluation indicator system for children's study desks was established, as illustrated in Fig. 2.

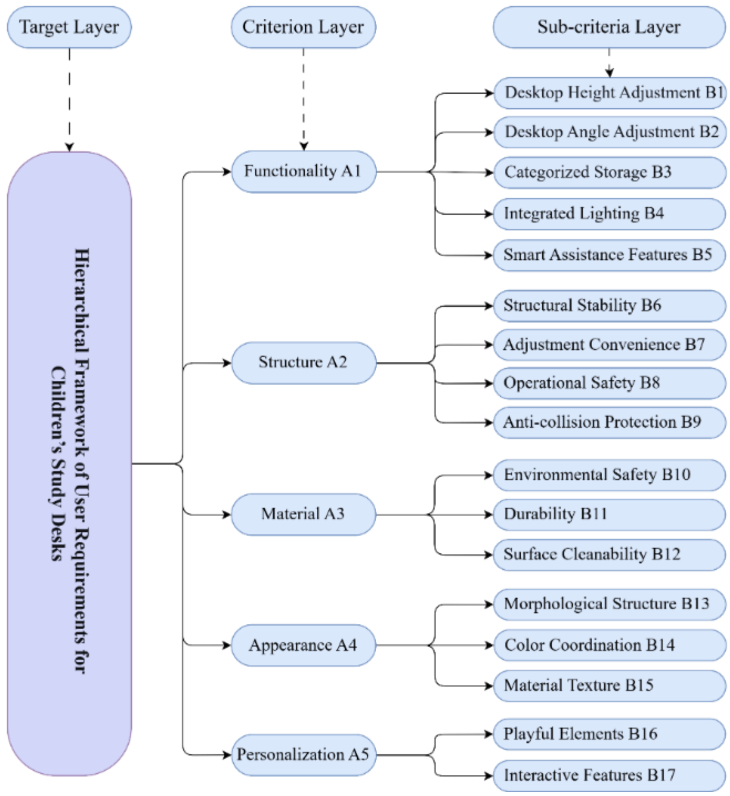

Fig. 2. Evaluation indicator system

Based on the evaluation indicator system illustrated in Fig. 2, ten experts were invited to participate in the AHP assessment, including three professionals from the furniture industry, three product designers specializing in furniture, and four industrial designers. The experts conducted pairwise comparisons of both the first-level and second-level indicators using the 1 to 9 scale. After scoring, the geometric mean of the evaluations for each criterion was calculated to represent the collective expert judgment. These geometric means were then used to construct the judgment matrices, which were subsequently normalized to compute the weight values for each evaluation indicator. The results of these computations are presented in Tables 2 and 3.

Table 2. Criterion Layer Indicators and Weights

Indicator	A1	A2	A3	A4	A5	weight
A1	0.598	0.653	0.634	0.466	0.432	0.552
A2	0.178	0.194	0.277	0.211	0.309	0.232
A3	0.128	0.095	0.136	0.130	0.198	0.136
A4	0.056	0.040	0.045	0.043	0.092	0.055
A5	0.041	0.019	0.020	0.014	0.030	0.025

Table 3. Overall Weights and Comprehensive Ranking

Indicator	A1	A2	A3	A4	A5	Overall Weights	Comprehensive Ranking
B1	0.517					0.285	1
B2	0.285					0.157	2
B3	0.107					0.059	6
B4	0.057					0.031	8
B5	0.035					0.019	11
B6		0.301				0.070	5
B7		0.052				0.012	13
B8		0.522				0.121	3
B9		0.126				0.029	9
B10			0.780			0.106	4
B11			0.155			0.021	10
B12			0.064			0.009	15
B13				0.755		0.041	7
B14				0.107		0.006	17
B15				0.138		0.008	16
B16					0.571	0.014	12
B17					0.429	0.011	14

The consistency of the evaluation indicator weights was assessed using Eq. 3. The Consistency Ratio (CR) values for both the criterion level and all sub-criterion levels were 0.0700, 0.0362, 0.0104, 0.0272, 0.0090, and 0.0000. Since all CR values were below 0.1, the judgment matrices met the consistency requirement, indicating that the pairwise comparisons were logically coherent and the results reliable.

Based on the finalized indicators and weights, three representative children's study desks with high sales and substantial user reviews were selected from a major Chinese e-commerce platform (Fig. 3).

Fig. 3. Three representative children's study desks

Product 1 is made primarily of paint-free rubberwood boards and cold-rolled steel. It features hand-crank height adjustment and manual desktop angle adjustment, along with partitioned storage. The structure includes a desktop, adjustable lifting legs, a multi-layer bookshelf, storage bins, and hanging organizers. A tablet holder is included, and all edges are rounded for safety. Product 2 is constructed from 100% solid rubberwood coated with natural wood wax oil and uses trapezoidal reinforced legs. It supports basic writing and reading functions and provides partitioned storage. Height adjustment is achieved manually through screw fixation. The structure consists of a desktop, solid-wood legs, an upper open shelf, and a lower drawer. Product 3 uses tempered glass and cold-rolled steel. It offers electric height adjustment with memory settings and an anti-collision rebound feature. Additional functions include wireless charging and multiple USB ports. Structurally, it includes a smooth white desktop, electric metal legs, and a side charging area.

Using the criteria weights obtained from the AHP method, the three selected children's study desks were further evaluated. To collect evaluation data, questionnaires were distributed both online and offline to 10 related experts and 20 parents who had experience purchasing and using such products. The evaluation adopted a 0 to 10 scoring scale, where the intervals were defined as follows: 0 < Very Poor ≤ 3, 3 < Poor ≤ 5, 5 < Average ≤ 6, 6 < Good ≤ 8, and 8 < Excellent ≤ 10. The arithmetic mean of all collected scores for each evaluation criterion was calculated to represent its final value, thereby establishing the initial decision matrix, as shown in Table 4.

Table 4. Initial Matrix

Indicator	Product1	Product2	Product3
B1	8.60	4.22	9.24
B2	8.42	2.86	4.40
B3	8.78	7.34	5.40
B4	1.90	1.74	1.70
B5	2.74	2.10	8.34
B6	8.10	8.58	8.00
B7	7.76	3.44	8.98
B8	8.90	8.18	7.40
B9	8.78	8.16	6.56
B10	8.74	9.20	6.20
B11	8.14	9.28	8.04
B12	7.14	7.02	8.82
B13	7.88	7.86	8.14
B14	8.30	7.30	7.82
B15	7.62	8.94	6.50
B16	8.60	5.14	4.96
B17	5.30	3.04	6.80

Design evaluation

The initial matrix was normalized by Eq. 4 to obtain a standardized evaluation matrix, as shown in Table 5. Subsequently, the AHP-derived criterion weights were applied to construct the weighted standardized decision matrix (Eq. 5). Positive and negative ideal solutions were determined (Eqs. 6 and 7), and the relative closeness to the ideal solution was calculated (Eq. 8). Higher closeness values indicate better overall performance. Based on these values, Product 1 ranked first, Product 3 second, and Product 2 third. The results are presented in Table 6.

Table 5. Standardized Evaluation Matrix

Indicator	Product1	Product2	Product3
B1	0.272	0.133	0.292
B2	0.266	0.090	0.139
B3	0.278	0.232	0.171
B4	0.060	0.055	0.054
B5	0.087	0.066	0.264
B6	0.256	0.271	0.253
B7	0.245	0.109	0.284
B8	0.281	0.259	0.234
B9	0.278	0.258	0.207
B10	0.276	0.291	0.196
B11	0.257	0.293	0.254
B12	0.226	0.222	0.279
B13	0.249	0.249	0.257
B14	0.262	0.231	0.247
B15	0.241	0.283	0.206
B16	0.272	0.163	0.157
B17	0.168	0.096	0.215

Table 6. Sorting Results

Term	The positive ideal solution distance S^+	The negative ideal solution distance S^-	Relative convergence T	Sorting results
Product 1	0.029	0.112	0.793	1
Product 2	0.117	0.038	0.244	3
Product 3	0.07	0.094	0.575	2

Evaluation validation

To validate the evaluation results, online review data for the three selected products were collected from the comment sections of their product detail pages on November 2, 2025, *via* a third-party review acquisition tool. The dataset mainly consisted of user reviews from the Taobao e-commerce platform. As these reviews were generated from individual consumer purchases, the content predominantly reflects home-use scenarios rather than institutional procurement. Initially, 4,350, 653, and 693 reviews were obtained for Products 1, 2, and 3, respectively. A standardized preprocessing protocol, consistent with established practices in online review mining, was applied to enhance data reliability. Duplicate entries were removed, promotional content was excluded, and emoji-only or semantically meaningless short comments (e.g., “good,” “ok”) were discarded. Reviews unrelated to product performance, such as logistics-only remarks, were also filtered out. Initial and follow-up comments from the same user were merged to avoid double counting. After preprocessing, 3,801 valid reviews for Product 1, 413 for Product 2, and 487 for Product 3 were retained.

The cleaned text data were then processed using the Jieba lexical analysis library for word segmentation, and word frequency statistics were visualized as word clouds for the three products (Figs. 4 through 6). Sentiment analysis was then performed using the DEEPSENTI model, a deep learning–based sentiment classification model that integrates word embeddings with contextual semantic representation to improve short-text sentiment detection accuracy. Compared with traditional lexicon- or rule-based approaches, DEEPSENTI better captures implicit emotional polarity and domain-specific expressions, making it suitable for large-scale e-commerce review analysis. Reviews were classified as positive, neutral, or negative. The sentiment results revealed that Product 1 received 3,770 positive, 17 neutral, and 14 negative comments; Product 2 received 360 positive, 9 neutral, and 45 negative comments; and Product 3 received 466 positive, 6 neutral, and 15 negative comments.

Market acceptance, defined as the proportion of positive reviews, was 99.18%, 86.96%, and 95.69% for Products 1, 2, and 3, respectively, yielding the ranking: 1 > 3 > 2. This order aligns with the AHP–TOPSIS evaluation, confirming the validity and robustness of the proposed framework.

Fig. 4. Word clouds of Product 1 (left), Product 2 (center), and Product 3 (right)

It is noteworthy that the high-frequency terms in the word clouds of the three products show considerable similarity. Across all products, frequent terms such as "Install," "solid," "Material," "quality," "Appearance," and "customer service" indicate that consumers consistently focus on assembly experience, perceived sturdiness, and material quality. This convergence suggests that mainstream children's study desks share similar baseline functional and perceptual attributes, particularly regarding build solidity and ease of assembly. However, despite these shared concern dimensions, the quantitative evaluation results still revealed performance differences among the products. This shows that while user attention centers on common foundational attributes, the AHP–TOPSIS model can distinguish finer performance differences beyond these baseline perceptions.

RESULTS AND DISCUSSION

Analysis of Weighting Results

The AHP results revealed a clear hierarchy among the five primary criteria: Functionality (A1) ranked highest, followed by Structure (A2), Material (A3), Appearance (A4), and Personalization (A5), indicating that experts prioritize children's learning needs, adaptability, and ergonomic comfort over visual or personalized features (Xiong *et al.* 2021). This aligns with previous ergonomics studies emphasizing usability and adaptability in children's furniture evaluation (Lee *et al.* 2018; Wang *et al.* 2024).

Within Functionality (A1), Desktop Height Adjustment (B1) and Desktop Angle Adjustment (B2) received the highest weights, reflecting the need to accommodate anthropometric diversity and physical growth (Chen and Zhang 2025). Adjustable mechanisms help maintain proper posture, reduce musculoskeletal strain, and improve comfort and focus (Koskelo *et al.* 2007; Oyewole *et al.* 2010). Categorized Storage (B3), Integrated Lighting (B4), and Smart Assistance Features (B5) were secondary, with storage rated most important among them. In Structure (A2), Operational Safety (B8) was the top priority, followed by Structural Stability (B6), Anti-collision Protection (B9), and Adjustment Convenience (B7), confirming that safety and stability underpin reliable functional operation. For Material (A3), Environmental Safety (B10) ranked far above Durability (B11) and Surface Cleanability (B12), highlighting expert concern over emissions such as VOCs and formaldehyde (Qi *et al.* 2019; Ulker *et al.* 2021) and reflecting a shift toward sustainable, health-oriented materials (Xiong *et al.* 2020; Zhu and Niu 2022; Karpudewan 2024; Xiao *et al.* 2024). Within Appearance (A4), Morphological Structure (B13) ranked highest, suggesting that balanced form and coherent proportions outweigh Color Coordination (B14) or Material Texture (B15). In Personalization (A5), Playful Elements (B16) were valued more than Interactive Features (B17), indicating a preference for imaginative forms or modularity. Considering all sub-criteria, the top overall indicators were B1, B2, B8, B10, and B6, followed by B3, B13, and B4. Lower-ranked factors included B5, B16, B7, B17, B12, B15, and B14. Overall, adaptability, safety, and material quality were the most influential dimensions. Designers should prioritize adjustable ergonomic mechanisms, low-emission materials, and stable structures, while user-friendly storage and lighting serve as secondary features. Aesthetic refinement and personalization may enhance engagement but are nonessential.

In conclusion, the AHP results support a layered optimization strategy: (1) prioritize adaptability and safety; (2) strengthen material health and structural stability; (3) enhance usability and functional convenience; and (4) enrich aesthetic and emotional value.

Comparison between AHP–TOPSIS Evaluation Results and Online Review Data

The sentiment analysis of online user reviews demonstrated the feasibility and robustness of the AHP–TOPSIS evaluation framework, confirming its ability to capture the key factors influencing user decisions accurately. A closer examination of the word cloud data further revealed a strong resonance between user perceptions and the weighting distribution of the proposed model.

For Product 1, frequently mentioned words such as “solid,” “stable,” and “robust” clustered together, directly corresponding to the high-weight indicator of Structural Stability in the AHP model. Simultaneously, frequent mentions of “material,” “rubberwood,” and “design” highlight users’ satisfaction with both the Material and Appearance dimensions. Terms like “adjustment,” “hand-crank,” “storage,” and “functionality” further reinforce its comprehensive performance in Functionality. This multidimensional positive feedback fully aligns with the model’s conclusion that Product 1 ranks first overall.

Product 2, a traditional solid-wood type, showed strengths in Material through terms such as “solid wood,” “stability,” “texture,” and “environmentally friendly”. The presence of negative expressions such as “odor,” “burrs,” and “wobble” suggests limitations in craftsmanship and quality control, underscoring the importance of precision manufacturing for material-based products.

Product 3 exhibited a clear technological orientation. Words including “lifting,” “electric motor,” “smooth,” and “automatic” align with Adjustment Convenience and Smart Assistance Features, while “charging,” “wireless,” and “appearance” reinforce its appeal in both aesthetics and functionality—consistent with its second-place ranking.

Although the overall ranking of user sentiment aligned with the AHP–TOPSIS results, the word frequency analysis also uncovered subtle insights that the model itself cannot fully capture, offering a deeper understanding for future optimization. One notable finding was the implicit weighting of service-related attributes. Across all three products, the term "installation" consistently ranked among the top keywords, frequently co-occurring with "technician," "customer service," "patience," and "home delivery." This pattern underscores that the overall purchase, installation, and after-sales experience—though not included in the initial theoretical model—exerts a decisive impact on user satisfaction. Therefore, future evaluation systems should consider incorporating service-related criteria as hidden yet influential dimensions of product perception. Moreover, user perceptions tend to be contextualized and concretized, both reinforcing and enriching the meaning of predefined indicators. For example, the indicator Environmental Safety manifests in user discussions as concerns about "odor," "smell," and "environmental friendliness." In Product 3, the emphasis on Smart Assistance Features gives rise to new experiential terms such as "silent," "sound," and "sensitivity." These concrete expressions provide valuable guidance for refining product design and engineering details.

CONCLUSIONS

1. A hybrid analytic hierarchy process – Technique for Order Preference by Similarity to Ideal Solution (AHP–TOPSIS) framework was developed for the comprehensive assessment of children's study desks. The framework effectively combines subjective expert judgment with objective ranking mechanisms, providing a structured and reliable decision-making tool for product evaluation.
2. The proposed framework demonstrated high practical feasibility, capturing the multidimensional attributes of children's study desks, including Functionality, Structural Design, Material, Appearance, and Personalization. Among these, Functionality and Structural Design were found to exert the most significant influence on product performance.
3. The comparison between AHP–TOPSIS evaluation results and online review sentiment analysis showed strong consistency, confirming the validity of the proposed model. This indicates that the integrated method can accurately reflect both expert assessment and real-world user perception.
4. The incorporation of online user data provided additional insights beyond traditional evaluation models, revealing latent factors such as ease of installation and service-related experiences that influence user satisfaction. These findings show the value of combining quantitative modeling with market feedback in product design evaluation.

ACKNOWLEDGMENTS

Conflict of Interest

The authors declare no conflicts of interest related to this work.

Use of Generative AI

The authors used ChatGPT (OpenAI, USA) only for language polishing and improving clarity of expression. No generative AI tools were used for data analysis, research operations, figure generation, or creation of scientific content.

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