Research on the Design Method of the Isomorphism of Logical Thinking and Perceptual Thinking

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***Abstract*—In the current era with an increasingly in-depth interdisciplinary integration, traditional design thinking is confronted with numerous challenges, making it urgent to construct innovative design thinking. This study focuses on the field of product development and is dedicated to exploring design methods that achieve the isomorphism of logical thinking and perceptual thinking. Through an in-depth study of the Axiomatic Design Theory, a structured functional design framework has been constructed, which encompasses investigations in the customer domain, the functional domain, and the CN - FR mapping relationship. This framework utilizes various methods and tools, such as brainstorming, Quality Function Deployment (QFD), and the Kano Model, to effectively transform Customer Needs (CN) into Functional Requirements (FR) and determine the mapping relationship between the two. To verify the effectiveness of the framework, an experiment was conducted on undergraduate students majoring in engineering design. They were divided into the logical group, the perceptual group, and the isomorphic group, and each group adopted design approaches dominated by different thinking modes to complete the design tasks of smart home devices. The experimental results indicate that the isomorphic framework significantly enhances the innovativeness of design schemes, improves the efficiency and accuracy of transforming user needs, and the design schemes of the isomorphic group exhibit excellent performance in the user satisfaction test. Additionally, this study also analyzes the differences between novice and expert designers in the functional design process and proposes corresponding teaching improvement measures. The research findings not only fill the gap in the collaborative application of multimodal thinking in design thinking research, providing a new perspective for design innovation and education, but also demonstrate great potential in the practice of product development, and are expected to promote the design industry to develop in a more user-oriented and innovation-driven direction.**

Keywords—Logical Thinking; Perceptual Thinking; Design Method; Product Development; Innovative Design

I. Introduction

Engineering design, as a highly creative human activity, encompasses two aspects: "doing the right things" and "doing things right". In the past, engineering design laid more emphasis on "doing things right", that is, generating and optimizing design schemes through various means. However, in recent years, people have increasingly realized that "doing the right things", namely formulating reasonable, meaningful, practical and unique design problems, is equally crucial (Hasan et al., 2024). In product development, functional design is the process of transforming customer requirements into functional requirements. Nevertheless, this process is confronted with numerous challenges, especially for novice designers. The outcome of functional design provides specific "targets" for subsequent design, and its importance is self-evident. The aim of this study is to propose a structured framework to assist novice designers in carrying out functional design more systematically, realizing the isomorphism of logical thinking and perceptual thinking, and thereby enhancing their innovative design capabilities.

II. Review of Related Work

A. Definition of Functional Design

Distinct from the common concept of functional modeling, the definition of functional design in this study is derived from the Axiomatic Design Theory. This theory posits four independent design domains. Functional design primarily entails the transformation of Customer Needs (CN) into Functional Requirements (FR), corresponding to the formulation process from requirements to functions (R → F) (Liu et al., 2020). In the design thinking process, functional design encompasses the "empathy" and "definition" stages and is also associated with the product planning and conceptual design segments within systems engineering design..

B. The Relationship between Functional Design and Design Thinking

Functional design plays a pivotal role in shaping designers' understanding of engineering design. Design thinking is multifaceted, encompassing the creation of new objects, problem-solving, reflective practice based on logical reasoning, and the creation of new meanings. Functional design is closely associated with these aspects, such as the "personal synthesis" of customer needs, the "orderly transformation" from CN (Customer Needs) to FR (Functional Requirements), the "creative exploration" of the functional domain, and the reshaping of product meaning under the influence of social constructivism.Nevertheless, functional design poses significant challenges for novice designers. In the problem definition stage, they tend to directly enter the solution space, lacking in-depth exploration of the problem. Moreover, they predominantly adopt convergent thinking and are less proficient in applying case-based reasoning and analogical design compared to expert designers.In addition, most engineering design courses do not attach sufficient importance to the teaching of functional design. The framework proposed in this study is mainly targeted at the innovative design of consumer products, and its applicability to industrial products and intermediate products may be limited.

C. Application and Practice of the Framework

1) Teaching Applications

The functional design framework has been continuously taught in engineering design courses at two universities for numerous years, including the graduate mechanical design course at the University of Southern California and the undergraduate engineering design course at the University of New South Wales (Liu et al., 2020). Meanwhile, this framework has also been imparted to professional designers, senior engineers, and business managers through design workshops (Rashid, 2020).During the teaching process, a project-based learning approach is adopted. Students complete design projects in groups and are required to submit three reports, including the functional design report. Their performance is evaluated based on aspects such as the novelty and quality of the design outcomes, the correct application of design methods, and the report format.Over the years of teaching, the framework has been iteratively improved in terms of methods, steps, procedures, requirements, and evaluation criteria.

2) Example Demonstration.

Taking "designing a kitchen product convenient for cooking" as an example, this section illustrates how the design team applies the framework.During the stage of identifying target customers and stakeholders, it is clearly defined that the target customers are college students aged 18 - 25, and the relevant stakeholders include manufacturers and distributors. The Voice of the Customer is collected through online surveys and interviews, and the problems that students encounter in cooking are identified, such as time-consuming, lack of kitchen utensils, and lack of variety in dish selection.In the stage of overall inferring customer needs, innovative functions are proposed by combining the trend of automation technology. When formulating functional requirements, relevant rules are followed and design constraints are determined. The functional requirements are classified by the Kano Model and the Long Tail Model.Finally, the House of Quality is constructed to manage the CN - FR (Customer Needs - Functional Requirements) mapping relationship, and design concepts that meet the functional requirements are generated. For instance, a kitchen appliance with automatic stirring, temperature control, and reminder functions is developed (Liu et al., 2013).

3) Analysis of the Differences between Novice and Expert Designs

Through the comparison of a large number of novice design reports (such as the 78 reports in the engineering design course at the University of New South Wales in 2018) with the design achievements of experts, the differences between novices and experts in the process of functional design have been summarized.When identifying target customers, novices are often restricted by their own experiences and tend to substitute personal experiences, which leads to deviations in design positioning. However, most of them can effectively apply the 4-P brainstorming method (Liu et al., 2020).In terms of collecting the Voice of the Customer, they mostly adopt traditional survey methods, seldom conduct iterative inquiries, and are deficient in obtaining key users and conducting on-site situational inquiries.When formulating functional requirements, although they can follow the format, it is difficult for them to achieve complete solution neutrality.In handling the CN - FR (Customer Needs - Functional Requirements) mapping relationship, although novices understand the QFD (Quality Function Deployment) method, they encounter difficulties in benchmark analysis due to the lack of actual data (Liu et al., 2020).

D. Functional Design Framework of the Isomorphism of Logical Thinking and Perceptual Thinking

1) Overall Framework and Process

For ambiguous problem statements, novice designers can gradually transform them into explicit problems through a structured process consisting of seven steps, thereby determining Customer Needs (CN), Functional Requirements (FR), and their mapping relationships (Liu et al., 2020). This process is divided into three stages: investigation in the customer domain, investigation in the functional domain, and investigation of the CN - FR mapping relationship. In each stage, the thinking mode of "listing - organizing - selecting" is followed to synchronously diverge and converge design thinking, ensuring that various factors are comprehensively considered and the most promising design directions are screened out.

2) Investigation in the Customer Domain

a) Determining Target Customers and Relevant Stakeholders

The target customers of the product should be clearly defined, namely the individuals or organizations that directly purchase, own, use, and maintain the product, along with the relevant stakeholders whose decisions can impact various aspects of the product within different contexts (Christensen et al., 2003). Designers can select different customer/stakeholder participation models based on the product category, such as design-for-customer, design-with-customer, design-by-customer, etc. (Liu et al., 2020). Through the theory of lead user, key users can be identified and incorporated. For instance, in the development of some functionally novel products, the participation of key users is of vital importance.

b) Collecting the Voices of Customers and Stakeholders

Designers can employ methods such as surveys, interviews, ethnographic research, and product review analysis to gather first-hand information (Liu et al., 2020). Ethnographic research is conducive to understanding customers' habits and the lifestyle significance of the product. It starts without preset assumptions and constructs explanations through abductive reasoning. Product reviews offer a wealth of information, yet systematic qualitative data analysis is required (Christensen et al., 2003). The voices of customers encompass multiple aspects, among which customer needs are the focal point of design attention and can be classified according to Maslow's Hierarchy of Needs theory.

3) Overall Inference of Customer Needs

The collected customer needs should be inferred within a broader social, industrial, or corporate context to identify innovative opportunities. This process requires consideration of macro-environmental factors, such as political, economic, social, and technological factors (the PEST framework), with particular emphasis on social and technological factors (Liu et al., 2020). For example, in the design of consumer electronics products, the lifestyle significance is an important social factor that varies across different cultural backgrounds and can influence product design. Technological factors such as the Internet of Things, virtual reality, and augmented reality are the driving forces for product innovation.

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B. Investigation in the Customer Domain

a) Determining Target Customers and Relevant Stakeholders

The target customers of the product should be clearly identified, namely the individuals or organizations that directly purchase, own, use, and maintain the product, along with the relevant stakeholders whose decisions can affect various aspects of the product in different situations (Liu et al., 2020). For instance, in the design of baby strollers, the target customers are parents, and the relevant stakeholders include regulatory agencies, material suppliers, and schools, etc. (Bijl-Brouwer et al., 2015). Designers can select different customer/stakeholder participation models according to the product category, such as design-for-customer, design-with-customer, design-by-customer, etc. (Schmidt et al., 2016). Through the theory of lead user, key users can be identified and incorporated. For example, in the development of some functionally novel products, the participation of key users is of crucial importance (Giourka et al., 2020). In addition, the Design Structure Matrix (DSM) can be used to reveal the relationships between customers and stakeholders (Durugbo et al., 2020)..

b) Collecting the Voices of Customers and Stakeholders

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c) Overall Inference of Customer Needs

The collected customer needs should be inferred within a broader social, industrial, or corporate context to identify innovative opportunities. This process requires consideration of macro-environmental factors, such as political, economic, social, and technological factors (the PEST framework), with particular emphasis on social and technical factors (Flostrand et al., 2019; Ali et al., 2024). For example, in the design of consumer electronics products, the lifestyle significance is an important social factor that varies across different cultural backgrounds and can affect product design (De Weck et al., 2022; Ponnusamy et al., 2024). Technological factors such as the Internet of Things, virtual reality, augmented reality, digital twin, blockchain, 3D printing, big data analysis, artificial intelligence, and advanced materials are the driving forces for product innovation. Taking the design of robotic vacuum cleaners as an example, its design needs to incorporate relevant technological factors (Kanaga Priya et al., 2024).

C. Investigation in the Functional Domain

a) Formulating Functional Requirements Based on Customer Needs

Designers are required to formulate Functional Requirements (FR) in accordance with customer needs, which involves several key issues. FR should be represented in a strict <verb + object> or <verb + object (in context)> format (Liu et al., 2020). For the design of mechanical and electromechanical products, the Functional Basis method can be referred to for establishing a universal functional vocabulary (Spalding et al., 2021). Each FR needs to be quantified into specific target values and an acceptable design range, which demands extensive design knowledge and experience (Zhang et al., 2024). Designers can also extract novel functions from similar products through a systematic function transfer process or draw inspiration from biological systems (Liu et al., 2024). Meanwhile, it is necessary to distinguish between customer needs and functional requirements, as well as between functional requirements and Design Constraints (DC). Design constraints are mostly imposed by third-party stakeholders. Different from the range specification of FR, DC are usually discrete values, such as regulations, environmental factors, cost, size, weight, etc. (Shi et al., 2024)

b) Classifying Functional Requirements

The Kano Model is employed to classify FR into four categories: attractive, one-dimensional, must-have, and indifferent, based on the two dimensions of the availability of FR and customer satisfaction (Zhang et al., 2023). The Long Tail Model, on the other hand, divides FR into two categories: popular and unpopular. The popularity of a function depends on the number of products carrying the same function in the market and their usage frequency (Wouters et al., 2022). There is an implicit connection between these two models, and the classification results can be cross-referenced (Tao et al., 2024). Traditionally, the Kano Model was used in combination with surveys and interviews. Nowadays, automated classification can be achieved through cloud computing technology. The information of the Long Tail Model can be obtained through online product review analysis (Guo et al., 2024). Based on the classification results, designers can assign different weights to different categories of FR according to the design objective. For example, in the design of consumer electronics products, attention can be paid to unpopular functions that can surprise customers to promote innovation (Shi et al., 2024).

c) Classifying Functional Requirements

Designers model the functional hierarchy to organize FR hierarchically according to the level of abstraction, or

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analyze the dependencies of FR using DSM (Design Structure Matrix) (Liu et al., 2024). This method can effectively reveal the relationships and priorities among functions (Liu et al., 2020).

Designers can organize FR in various ways. For example, they can construct a functional hierarchy to accommodate FR hierarchically according to the level of abstraction, which can reflect the hierarchical and compositional relationships among FR (Liu et al., 2020). The IDEF0 method can be used to model each FR and integrate them into a functional chain to show the energy, material, and signal flows of the product (Shi et al., 2022). The Functional Design Structure Matrix (DSM) is used to reveal the interdependencies among FR. These methods provide systematic support for the logical organization of functional requirements (Wang et al., 2021). Different design structures can reveal FR information from different perspectives and can be flexibly applied in practice according to needs (Liu et al., 2020)

D. Investigation of the CN - FR Mapping Relationship

Finally, designers need to manage the coupling relationship between CN (Customer Needs) and FR (Functional Requirements) by applying the Quality Function Deployment (QFD) method and construct the House of Quality (HoQ). In the House of Quality, the selected CN from Step 2 and the selected FR from Step 4, as well as information such as the coupling relationships between them, functional coupling relationships, and benchmark analysis results, are accommodated (Gupta et al., 2023). Based on the weighting results from Step 3 and Step 5, the priorities of CN and FR are determined, and designers should focus on these priorities in the subsequent conceptual design (Liu et al., 2020).

IV. EXPERIMENTAL DESIGN AND IMPLEMENTATION

A. Experimental Objectives

The aim of this experiment is to verify the effectiveness of the isomorphic framework of logical and perceptual thinking in functional design, and to explore its specific roles in enhancing innovative capabilities, improving the efficiency of demand transformation, and enhancing user satisfaction.

B. Experimental Hypotheses

H1: The isomorphic framework can significantly enhance the innovativeness of design solutions.

H2: The isomorphic framework improves the efficiency and accuracy of transforming user needs into functional requirements.

H3: The solutions designed with the isomorphic framework will obtain the highest scores in the user satisfaction tests..

C. Experimental Subjects

1) Participants

Thirty undergraduate students majoring in engineering design were randomly divided into three groups:

The Logic Group: Dominated by logical analysis.

The Perceptual Group: Dominated by perceptual creation.

The Isomorphic Group: Combining logical and perceptual thinking.

2) Tasks

To design a smart home device that meets the demands of young users aged 18 - 35 for personalized functions.

3) Sample Size

Each group was required to complete at least ten design proposals, totaling thirty proposals.

D. Experimental Conditions

1) Experimental Environment

Equipped with virtual reality (VR) devices for simulating user tests.

Provided with design support tools, including QFD forms, user empathy map templates, and Kano model classification tools.

2) Experimental Period

The design period for each group was two weeks, covering demand analysis, functional design, proposal generation, and optimization.

E. Experimental Process

The experiment was divided into four stages, and the tasks and methods of each stage are detailed as follows:

Stage 1: User Demand Analysis

Objective: To uncover both explicit and implicit user demands to provide inputs for functional design.

Methods:

Questionnaire Survey: Designed 15 multiple-choice questions regarding smart home demands to collect user preferences.

Interviews: Each group interviewed 5 users to gain in-depth understanding of usage scenarios and potential demands.

Text Analysis: Analyzed 200 online reviews of smart home products to extract demand keywords.

Outputs:

A list of user demands, classified according to Maslow's Hierarchy of Needs theory.

Each of the three groups generated explicit demands (basic, performance) and implicit demands (charm, emotional).

Stage 2: Demand Transformation and Functional Decomposition

Objective: To transform user demands into Functional Requirements (FR).

Methods:

Logic Group: Employed QFD forms and Functional Design Structure Matrix (DSM), focusing on demand quantification.

Perceptual Group: Utilized user empathy maps and brainstorming to stimulate creative functional demands.

Isomorphic Group: Combined the two methods to comprehensively analyze functional performance and emotional value.

Outputs:

Each group submitted a list of functional requirements, clearly defining the quantification targets of each requirement.

Functional requirements defined in the format of <verb + object + situation>.

Stage 3: Proposal Generation and Optimization

Objective: To generate multiple design proposals and optimize their priorities.

Methods:

Brainstorming: Each group generated 3 - 5 preliminary design proposals based on the demand list.

Functional Classification:

Applied the Kano model to classify functional requirements (must-have, performance, charm, no-difference).

Screened unpopular but user-surprising functions based on the Long Tail model.

Functional Organization: Constructed functional hierarchy structures and design structure matrices.

Outputs:

The three groups submitted functional hierarchy diagrams and final design proposals.

Stage 4: User Testing and Feedback

Objective: To evaluate the performance of design proposals in actual usage scenarios.

Methods:

Used VR technology to simulate user scenarios to test the functionality and experience of design proposals.

Collected user ratings, covering the following indicators:

Ease of use, aesthetics, innovativeness, and overall satisfaction (Likert scale, 1 - 7 points).

Outputs:

User testing reports, including quantitative ratings and qualitative feedback.

F. *Data Collection and Analysis*

1) *Data Collection*

User Needs:

Questionnaire: Generate the proportion of demand types (basic needs, performance needs, charm needs, no-difference needs).

Interviews and Reviews: Extract explicit demand keywords and implicit demand trends.

Functional Requirements:

Quantity and classification distribution of the functional requirements lists of each group.

Proposal Innovativeness:

Have five experts evaluate the innovativeness of each proposal (scoring from 1 to 10).

User Satisfaction:

Quantify four indicators (ease of use, aesthetics, innovativeness, overall satisfaction) through user ratings.

2) *Data Analysis*

Statistical Methods:

One-way Analysis of Variance (ANOVA): Compare the significant differences in the innovativeness scores of the three groups of design proposals.

Chi-square Test: Analyze the differences in the classification distribution of functional requirements.

Independent Samples t-test: Compare the differences in user satisfaction scores between groups.

Visualization Methods:

TABLE I. PIE CHART OF USER NEED CLASSIFICATION.

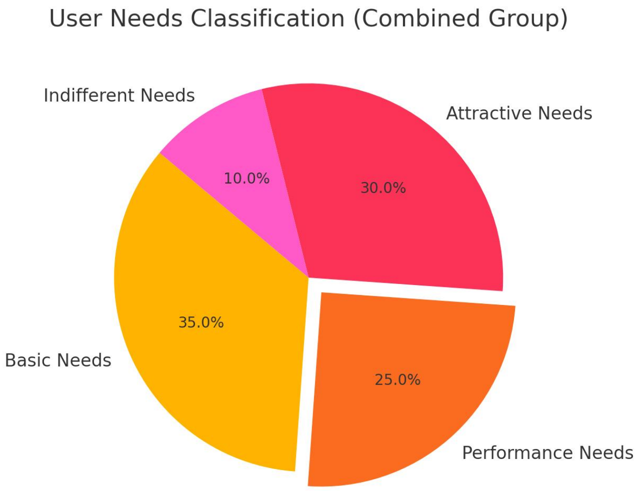


TABLE II. KANO BAR CHART OF MODEL DEMAND DISTRIBUTION

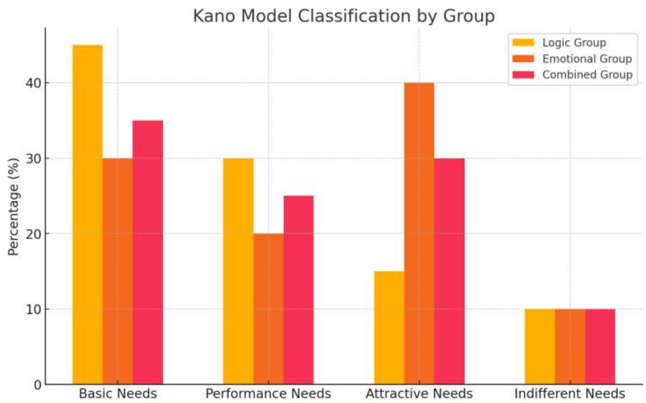


TABLE III. BOX PLOT OF PROPOSAL INNOVATIVENESS

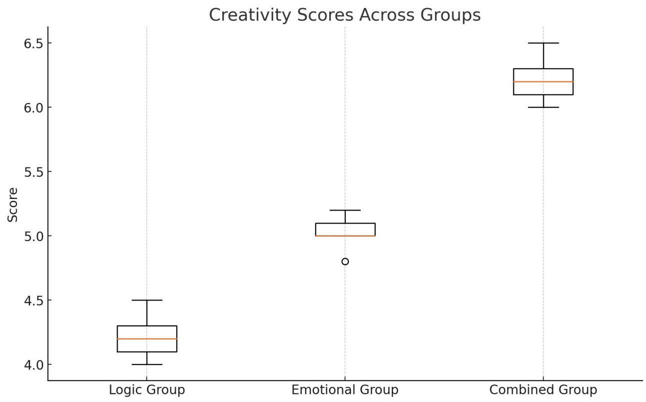
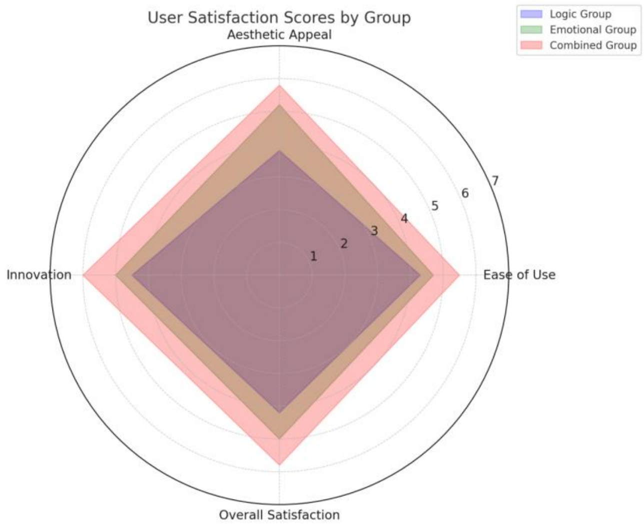


TABLE IV. RADAR CHART OF USER SATISFACTION



G. Discussion and Conclusions

1) Discussion Significant Advantages of the Isomorphic Framework

The experimental results have verified the effectiveness of the isomorphic framework of logical and perceptual thinking in functional design:

Enhanced Innovativeness

The proposals designed by the isomorphic group scored significantly higher in terms of innovativeness than those of the logic group and the perceptual group. This indicates that the combination of logical and perceptual thinking can compensate for the limitations of a single thinking mode, providing more abundant sources of inspiration in aspects such as demand exploration, function definition, and proposal generation (Christensen et al., 2016).

Significantly Improved User Satisfaction

In terms of the four indicators of ease of use, aesthetics, innovativeness, and overall satisfaction, the isomorphic group outperformed the other two groups. Particularly in aesthetics and innovativeness, the advantages were especially prominent. This shows that the isomorphic framework can better balance functional performance and emotional appeal while focusing on user needs (Demirbilek et al., 2003).

2) Complementary Roles of Logical and Perceptual Thinking

Logical Thinking

The logic group excelled in functional decomposition, demand mapping, and performance optimization, making it suitable for structured and goal-oriented design tasks. However, it paid insufficient attention to user experience and emotional value (Chien et al., 206).

Perceptual Thinking

The perceptual group was outstanding in capturing users' implicit needs and stimulating creativity, generating proposals with greater emotional appeal. However, it was relatively weak in demand quantification and function optimization (Desmetv et al., 2007).

Isomorphic Framework

By integrating logical and perceptual thinking, the isomorphic group overcame the deficiencies of a single thinking mode. It could ensure the scientific and functional nature of the design while also paying attention to emotional value and user experience, achieving the design goal of balancing innovativeness and practicality (Liedtka et al., 2015).

3) Insights from the Functional Classification of the Kano Model

Logic Group's Bias towards Must-Have Functions: The logic group focused more on the basic functional needs of the product to ensure reliable performance and clear goals (Xu et al., 2024).

Perceptual Group's Focus on Attractive Functions: The perceptual group tended to develop functions that could surprise users but lacked comprehensive coverage of must-have and performance functions (Zhou et al., 2024).

Isomorphic Group's Achievement of Balance: The isomorphic group achieved a good balance in the development of attractive and performance functional needs. By effectively organizing functional requirements, it demonstrated higher systematicness and coordination (Yi et al., 2024).

4) Practical Significance of User Feedback

The feedback from users during the testing phase indicated that the proposals designed by the isomorphic group were more in line with actual usage scenarios and could provide satisfactory functional experiences and emotional values. This is consistent with the characteristic of the isomorphic framework that takes both explicit and implicit needs into account during demand exploration and mapping (Xiaoning et al., 2024). The experiment also showed that designs relying solely on logical or perceptual thinking often struggle to fully meet users' multi-level needs (Yi et al., 2024).

5) Limitations of the Experiment

Sample Size: Using only 30 designers as experimental subjects may limit the universality of the results (Xu et al., 2024).

Product Type: The experiment focused on consumer smart home products, and other complex systems or industrial products may require further verification (Zhou et al., 2024).

Time Limit: The experimental period for each group was two weeks, which may not fully reflect the performance of designers in long-term iterations (Yi et al., 2024).

6) Conclusions

Theoretical Significance:

The isomorphic framework of logical and perceptual thinking proposed in this study has verified its advantages in functional design through experiments, filling the gap in the collaborative application of multimodal thinking in design thinking research. The framework theoretically further expands the definitions of logical and perceptual thinking and their interactions, providing a new perspective for design innovation and education.

Practical Significance:

The application of the isomorphic framework in product development can help novice designers carry out functional design more systematically, improving their innovation capabilities and the efficiency of transforming user needs. The experimental results indicate that the isomorphic framework is suitable for the design of consumer products with high requirements for user experience and has the potential to be extended to other fields.

Future Prospects:

Multi-Field Verification: Apply the isomorphic framework to industrial products and complex system designs to verify its applicability in various design tasks.

Expand Data Scale: Increase the sample size and invite participants with different backgrounds (such as senior designers, interdisciplinary teams) to participate in the experiment.

Tool Development: Develop auxiliary design tools based on the framework, such as an artificial intelligence-driven demand exploration platform or a functional requirement visualization tool.

Teaching Application: Further promote the isomorphic framework in engineering design education to help students master the collaborative methods of logical and perceptual thinking.

In conclusion, the isomorphic framework of logical and perceptual thinking provides designers with a systematic and flexible method, which helps to solve complex functional design problems and promotes the development of the design industry in a more user-oriented and innovation-driven direction.

V. Application and Practice of the Framework

1) Teaching Application

The functional design framework has been continuously taught for many years in engineering design courses at two universities, including the graduate mechanical design course at the University of Southern California and the undergraduate engineering design course at the University of New South Wales (Lin et al., 2021). Meanwhile, it has also been imparted to professional designers, senior engineers, and business managers through design workshops (Chandrasekaran et al., 2013). During the teaching process, the project-based learning method is adopted. Students work in groups to complete design projects and submit three reports such as the functional design report. They are evaluated based on aspects such as the novelty of the design results, quality, correct use of design methods, and report format (Jiang et al., 2023). The framework has been iteratively improved over the years in terms of methods, steps, procedures, requirements, and evaluation criteria.

2) Example Demonstration

Taking "designing a kitchen product for convenient cooking" as an example, it shows how a design team applies this framework. During the stage of determining target customers and stakeholders, the target customers are clearly identified as college students aged 18 - 25, and the relevant stakeholders include manufacturers, distributors, etc. Through online surveys and interviews, the voices of customers are collected. Problems faced by students in cooking, such as time-consuming, lack of variety in kitchen utensils and dish selections, are discovered, and thus customer needs are determined. During the stage of overall inference of customer needs, innovative functions are proposed in combination with the trend of automation technology. When formulating functional requirements, relevant rules are followed and design constraints are determined. The functional requirements are classified by the Kano model and the Long Tail model, and the functional hierarchy structure is constructed and adjusted and optimized. Finally, the House of Quality is constructed to manage the CN - FR mapping relationship, and design concepts that meet the functional requirements are generated, such as a kitchen appliance with functions like automatic stirring, temperature control, and reminders.

3) Analysis of Design Differences between Novices and Experts

Through the comparison of a large number of novice design reports (such as 78 reports in the engineering design course at the University of New South Wales in 2018) with expert design results, the differences between novices and experts in the functional design process are summarized (Liu et al., 2021). Novices are often limited by their own experiences when determining target customers, substituting personal experiences, which leads to design positioning deviations. However, most of them can effectively use the 4-P brainstorming method. Their main challenge lies in distinguishing between purposes and problems (Ejichukwu et al., 2023). In terms of collecting the voices of customers, they mostly adopt traditional survey methods, seldom conduct iterative inquiries, and have deficiencies in obtaining key users and conducting on-site situation inquiries (Meinel et al., 2020). When inferring customer needs, due to lack of experience, they have difficulty in making effective inferences in the corporate environment and understanding emerging technological factors, but they perform relatively well in identifying social factors and lifestyle significance (Cheng, 2023).

When formulating functional requirements, although they can follow the format, it is difficult for them to be completely solution-neutral. They often need to make iterative adjustments and are prone to confusing functional requirements with design constraints, and they do not consider the constraints in the specific project context adequately (Zheng et al., 1993). In terms of classifying and organizing functional requirements, some novices classify based on actual data, but still half of them rely solely on subjective estimates or do not refer to reliable data. The functional hierarchy decomposition is not effective enough, and they have difficulty in analyzing functional coupling (Byrne et al., 1993). In handling the CN - FR mapping relationship, although novices understand the QFD method, they have difficulties in benchmark analysis due to lack of actual data, and some novices still enter the solution space too early in the design process, which is opposite to the problem-solution co-evolution direction of experts (Nevaranta et al., 1993).

In response to these differences, corresponding teaching improvement measures have been proposed, such as introducing industry partners to provide data, encouraging students to iterate, and increasing case studies and interdisciplinary content.

VI. Research Limitations and Future Perspectives

1) Limitations

The iterative development of the current research framework is likely to be affected by the author's design thinking, which may introduce some biases. Given that it is built upon the Axiomatic Design Theory, adjustments might be necessary when attempting to align it with other design theories such as the Systems Engineering Design Methodology. Additionally, while functional design is intrinsically linked to conceptual design, this study has not delved comprehensively into the overarching synergy between the two aspects.

2) Future Outlook

Going forward, efforts will be made to introduce this framework in a broader range of design courses at diverse levels, inviting designers with multidisciplinary backgrounds to engage in practical applications. This will further validate and refine the framework. The plan is also to incorporate a wider variety of relevant design methods and develop different variants of the framework to enhance its adaptability across different contexts. Mixed-methods research will be carried out, combining quantitative and qualitative approaches to explore the profound impacts of functional design on multiple dimensions of design thinking, including object creation, problem-solving, reflective practice, and meaning-making. Controlled experiments will be designed to meticulously analyze the disparities in functional design approaches between novice and expert designers, thereby furnishing more targeted guidance for design education and professional practice.

VII. Conclusions

The functional design framework of the isomorphism between logical thinking and perceptual thinking proposed in this study is based on the Axiomatic Design Theory. It integrates a variety of related theories and methods, thus providing systematic guidance for novice designers' innovative design thinking in product development. Through its application in teaching and the analysis of practical cases, the feasibility and effectiveness of the framework have been verified. Meanwhile, the differences in the design processes between novices and experts have been identified, which provides a basis for further improving design education and enhancing design capabilities. Although there are certain limitations, the future research directions will contribute to promoting the development of this field and offering more powerful support for product development and design.

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