Reform of Product Design Teaching
Based on Bionic Concepts

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Various innate beauty and wonderful operation exist in nature. Biological features and strategies of organisms applied to product development has become a popular approach on contemporary product design. This study used a verification method – to apply the practical teaching – to obtain a set of methods on bionic design and product development. Through LAMDA methods of lean thinking, we focused on users’ actual requests of target products and their value, and a Mandala Chart for biological strategies and forms of bionic targets, resulting in a bionic Mandala Chart incorporated into product development to have products with bionic functions. Finally, via a fuzzy comprehensive evaluation (FCE) to evaluate students’ design, we found that the proposed approach can help them quickly grasp the relationship between thinking models and directions, and simplify operation on design process. With maximum degree of membership on design, experts’ evaluation suggested “good” or above can improve the efficiency of product development, and indeed help students realize practical use of bionic design. Results were as references for product design courses.

Keywords: Design Education; Bionic Concept; Lean Thinking; Mandala Chart; Fuzzy Comprehensive Evaluation (FCE)

1 Introduction

Everything in nature has been the object of imitation since ancient times. For example, on ancient battlefields, soldiers would wear tiger-shaped helmets to intimidate the enemy; their boots would be decorated with wing-shaped ornaments to convey the image of speed; in the age of modern science, sports cars would imitate the streamlined shape of the cheetah to create a sharp and powerful sense of speed; and even swimsuits have been made using the special skin structure of sharks to reduce water resistance.

Bionic design is an emerging interdisciplinary subject based on bionics and design applications. Design inspiration is obtained through observing and studying the biological characteristics in nature, and then reasonably apply it to design work after analysis and processing (Quan et al., 2019). When using bionics to handle problems in industrial design, it is more enlightenment than a simple imitation, but emphasizes the subjective initiative of designers to highlight the visual features through analogy (Xu, 2019). However, how to effectively transform the bionic pattern into the conceptual elements of product design and introduce them into the product development plan is still a problem to be solved, and there is no clear process for bionic design for teaching staff in the design field. So, the traditional design thinking process not only causes users to feel hesitant, but also fails to provide a clear framework for subsequent product development to link the concept to product engineering parameters. All of this makes it difficult to implement the practical applications of design education, and the design results cannot meet the needs and expectations of users. In order to solve the development dilemma, this study applies Lean Process and Product Development (LPPD) combined with the optimized Mandala Chart to assist product design teaching and complete bionic design examples.
2 Literature Review

2.1 Bionics
The term “bionics” was coined by J. E. Steel in 1960 and is defined as a kind of system science. The development of its function is based on a living system, and is an application of the principle of imitating biology in design and art. It establishes the adaptive research on the beauty of nature, human sensibility and the interaction between humans and objects, and introduces the research results into human life. Bionic design is different from the old application of bionics. It takes the “shape,” “color,” “sound,” “function” and “structure” of all things in nature as research projects (Zhang, 2009), combining some of the characteristic principles with the research results of bionics and applying them in the design process to explore new concepts, principles and methods for design. At present, the cases of bionics application in various design fields are increasing day by day, and it has become an important design technique for mankind.

2.2 Application of Bionic Creative Strategy Design and Modeling Design
Referring to the microstructure of butterfly wing scales and the principle of light reflection, and supplemented by nanotechnology, we have successfully developed environmentally friendly color-rendering fibers without chemical dyes, which is helpful for various fabric design applications (Yuan, 2019). Another example is shark’s skin covered with placoid scales, and the diversion grooves between scales that have good fluid drag reduction effect. After simulated application on swimwear, it can improve the performance of swimmers (Fu, 2017). At present, most of the product design teaching methods about bionic application only focus on bionic modeling, and only a few of them apply bionic strategy to product design. Through observation, designers can become familiar with the shape changes of natural creatures, and can use ingenuity to create products of different shapes. In furniture design, designers often use realistic techniques to illustrate concrete products, such as the Peapod lamp designed by Haas D’Amato Dorfman is designed in the shape of a large pea; the table legs of the Pepper table designed by Craig Nutt in 1989 was designed in the shape of red peppers, and the master of organic design, Ross Lovegrove designed the DNA ladder for his studio, which achieve a “natural” balance in form, materials and technology. Design and creation activities should be based on the formal rules of artistic beauty such as proportion, balance, rhythm, harmony and emphasis, to properly model various products, so as to shape the new product to meet aesthetics requirements, and achieve harmony and perfection between products and people through the structural function of the products (Lin, 1993).

2.3 Lean Thinking
The product development process under lean thinking follows the LAMDA method “Look, Ask, Model, Discuss, Act” proposed by Duward Sobek (Ulonska & Welo, 2013). It has clear process structure, method tools, thinking logic and the process of convergent thinking, and can effectively realize customer value, so it is worthy of enterprise introduction (Radeka, 2015). The LAMDA cycle (Figure 1.) allows the visualization of the problem and proposes solutions that lead the application of each of the elements, trying to fix the learned lessons and provide a discussion model to encourage the tacit knowledge (Saad et al., 2013). However, in the creative development stage of Lean Thinking, the creative principles and how to implement product modeling design are still not clear enough. This research uses bionics as the subject, and applies the biological strategies and biological modeling in the process of lean thinking product development to make up for the deficiencies of lean thinking.
2.4 Mandala Chart

Mandala is derived from Buddhism and is a transliteration in Sanskrit. It was originally a special term of Vajrayana, and is represented in the form of a nine-square grid arranged in a certain way. It uses the interaction of stimulus response and relaxation psychology to destroy cognitive inertia, thereby training individual creativity (Imaizumi, 1999) and effectively improving the user’s association ability (Lin, 2006). The Mandala Chart method is a thinking strategy proposed by Imaizumi Hiroaki (1977), which advocates abandoning the traditional linear note-taking method, expanding the thinking field as far as possible, and helping to diffuse thinking. With the Mandala note-taking method, you can write anything in any area (grid). It is a kind of “visual thinking” in which the subject is written in the center and the thoughts or associations arising from the subject are written in the other eight grids. There are no specific rules of operation. “3 × 3” is the basic simple grid use. There are two modes of operation: diffusion type (spreading in all directions) and surrounding type (flowing clockwise) (Figure 2.), which are also known as horizontal thinking and vertical thinking. By taking notes in this way, the Mandala graphics can be used to systematize and give a sense of direction. Then our potential can be continuously stimulated under continuous response, and we can develop creativity, find problems immediately, improve the efficiency of study and work, and improve the form of conscious thinking.

Figure 1. The LAMDA cycle

Figure 2. The Mandala chart diffusion mode and surrounding mode

However, such a drawing pattern may make users hesitant, and it is not easy to clearly show the way of correspondence between the grids. Therefore, the Mandala chart is used to draw a table for the main concept, with the center placed with “subject,” and then “main factors” can be filled in the diffusion or surrounding mode. Finally, the figure can be completed by filling in “secondary factors” by diffusion or surrounding (Figure 3.). This research explores the biological strategies and biological modeling of bionic objects by using the Mandala chart, and then introduces the summarized Mandala chart into the causal diagram of the lean thinking product development process to endow the product function with bionic creativity.
2.5 Morphological Structure of Sundew

Sundew (English Name: sundew; scientific name: Drosera indica), also known as Drosera intermedia, commonly known as Cordyceps sinensis, is a perennial hygrophytic insectivorous plant, which usually grows on wet grassland or by the waterside, and grasslands beside pine forests, etc.; Insectivorous plants are the result of long-term evolution. They usually grow on wet and acidic land with poor fertility, where the nutrients in the land are washed away by rain. Therefore, they must make up for it by catching insects. Some studies have confirmed that 50 - 76% of the nitrogen in Drosera intermedia comes from insects. The growth height of Sundew is about 6-50cm, and its roots are spherical; the stems are thin and upright; and the leaves are elongated and are covered with glandular hairs and secrete mucus. Drosera flowers are white and reddish in color. The growth temperature varies with species, the lowest temperature is 4°C, the highest temperature is 38°C, and the average temperature is about 20-26°C. Some species will become dormant when the temperature is too high or too low. The suitable relative humidity for growth should be more than 90%, and the dormancy period should be kept dry. (Table 1.)

Morphological characteristics of Droseraceae:
(1) Roots: the root system is simple and fragile; Sundew has adventitious roots. (2) Stem: the stem is slender and solitary; the length of the stem is about 15-20cm and is yellowish green or light green. (3) Leaves: Sundew leaves are all odd-shaped leaves, which cling to the stem and are elongated in shape, with dense red glandular hairs on the surface. The glands secreted at the top are sticky. The length of the leaves is about 5-12cm, and the color is green or yellowish green. The new leaves are curly. Glandular hairs mostly cover the upper epidermis, secreting mucus and digestive juices. (4) Reproductive organ: racemes. The calyx is bell shaped, divided into five lobes near the base; there are five petals in an inverted egg shape, about 4-6mm in length, and are white or slightly red or purple in color; There are five for male flowers, and the ovary is spherical in shape. There are five linear styles and fimbriate stigma; the pollen is yellow and triangular in shape, which is classified as interclass acute-angled, with a diameter of 51-71μ. (5) Seeds: the capsule is 3-5-lobed, the seeds are small and black, with a length of 294-353μ and a width of 175-216μ. (6) Color: the stems and leaves are light green or yellowish green, forming a strong contrast with the red glandular hairs. (7) Insect catching: when the insect comes in contact with the mucus secreted by the glandular hairs and are trapped by its sticky mucus, its instinctive struggle causes pressure on the leaf, causing the leaf to curl and cover the prey, which stimulates the gland to secrete more digestive juice. Sundew can be divided into two types: petiolate and sessile. There are seven kinds of glandular hairs, which are different in function, length, appearance, distribution and quantity. Also, due to the difference in the length of the glandular hairs, the appearance of Drosera with long stalks emerges. However, these elements cannot be used directly but simplified based on modern aesthetic and user demand. (Liu & Zhang, 2018) (Table 2.)
Table 1. Types of Sundew glandular hairs

<table>
<thead>
<tr>
<th>Form</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Petiolate long glandular hairs</strong></td>
<td>It is composed of the head and stem, and is the longest of all glandular hairs. The length of the stem is about 8 mm, the head is reddish, about 1 mm in length, and there are glandular cells that can secrete mucus. Petiolate long glandular hairs only exist at the edge of the leaf blade, with two staggered rows on each side.</td>
</tr>
<tr>
<td><strong>Petiolate medium-length glandular hairs</strong></td>
<td>The same as Petiolate long glandular hairs, with head and stem. The length of the stem is about 5 mm, and the head is about 1.5 mm. The glandular cells can secrete mucus. It is mainly distributed in the center of the leaf in three rows. The number of rows gradually decreases from the base to the tip of the leaf, but not to the uppermost tip part.</td>
</tr>
<tr>
<td><strong>Petiolate short glandular hairs</strong></td>
<td>The length of glandular hairs vary from 1.5 mm to 2.0 mm. The head is composed of one cell, similar to the head of Lentinus edodes, and has no ability to secrete mucus. It is mainly distributed on the edge, lower epidermis and leaf stems.</td>
</tr>
<tr>
<td><strong>Petiolate Bifurcation glandular hairs</strong></td>
<td>The length is close to that of petiolate short glandular hairs, The head is composed of four cells, and the two cells at the tip are bifurcated, like the tentacles of a snail. It is distributed on the whole plant, mainly on the upper and lower epidermis of leaves and stems, and has the largest number among all kinds of glandular hairs.</td>
</tr>
<tr>
<td><strong>Sessile globular glandular hairs</strong></td>
<td>It is composed of a single cell and appears globose on the epidermis with the ability to secrete mucus. It only exists on the stem with petiolate long glandular hairs and only exists from the base to two-thirds of the stem.</td>
</tr>
<tr>
<td><strong>Sessile piece glandular hairs</strong></td>
<td>It is disc-shaped with a coverage area of about 2.5 times that of the junction. The overall number is very small, it only exists in petiolate long glandular hairs, only 1-2 per stalk.</td>
</tr>
<tr>
<td><strong>Petiolate flat-head glandular hairs</strong></td>
<td>It is umbrella-shaped, about 1 mm in length, similar to petiolate short glandular hairs, but has a flat head. It only exists near the base of the leaves in very small quantity.</td>
</tr>
</tbody>
</table>
Table 2. Capture of Sundew design elements

<table>
<thead>
<tr>
<th>Part</th>
<th>Observation</th>
<th>Simplification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stem and Leaf</td>
<td>The stems of Drosera are radial. The length of the glandular hairs on the inner leaf surface is different from that on the outside. The length of the glandular hairs on the leaf edge is the longest. The ratio of the length of the inner and outer surface glandular hairs is about 1:3 to 1:5, and the density of the inner and outer hair distribution is also different. Capture this kind of difference for the concept of modeling.</td>
<td><img src="image1.png" alt="Images" /></td>
</tr>
<tr>
<td>Glandular hair</td>
<td>Observe the glandular hairs on the leaf surface and simplify the shape outline. The petiole and petiole head secreting mucus look like the structure of a cotton swab. With a large head and thin body, the petiole has toughness and elasticity.</td>
<td><img src="image2.png" alt="Images" /></td>
</tr>
<tr>
<td>Petal</td>
<td>Deconstructing the flowers of the Sundew, we can see the number of petals is a fixed five petals, white or slightly reddish purple. The petals are uniformly radial, with an average length of about 4-6mm, which can be enclosed by a circle.</td>
<td><img src="image3.png" alt="Images" /></td>
</tr>
</tbody>
</table>
3 Methodology
The design pattern proposed in this research takes the LAMDA method of lean thinking as the main structure (Ulonska and Welo, 2013), supplemented by the Mandala Chart to explore the biological strategy and biological modeling of bionic objects, and then introduces the summarized bionic Mandala chart into the causal diagram of lean product development process, and endows the product function with bionic concept creativity. In addition, since traditional lean thinking does not evaluate the design results, and consumers’ preference for product design is often fuzzy. Therefore, Fuzzy Comprehensive Evaluation (FCE) is used to evaluate the fuzzy attributes of the design results.

3.1 The Research Process
Part I: Market / competitor analysis
The subject analysis and object analysis are carried out for the target competitive products.

Part II: Customer value analysis / using the theory of Jobs to be done (JTBD) (Hankammer et al., 2019)
Step 1: After determining the product target for design, plan and implement the contextual inquiry
Observe the work site or local objects in person.
Think aloud: customers / users express their ideas while performing their work (Hertzum, 2015).
Researchers record key events.
Interview details (make detailed inquiries about the key events observed).
Integrate the field notes.
Step 2: Quantitative contextual inquiry results
Turn the key events into questionnaire items of satisfaction and importance.
Step 3: Information visualization
• Convert the questionnaire score into opportunity score (and visualize it)
• Obtain the sequence of customer value according to the opportunity score, and take all Opp > 10 customer value as the main design criteria of product creative ideas.

Part III: Formulate product strategy and summarize into an A3 report (Saad et al., 2013).
Part IV: Draw the causal map (Cloft et al., 2018) / trade off curve / bionic Mandala Chart / Extraction and simplification of bionic design elements (Liu & Zhang, 2018).
Part V: Set-Based Development
Introduce the bionic Mandala chart into the set-based development synchronously. Find out the analogy relationship between “customer value” and “bionic concept” through the thinking mode of analogy to help the design development. Find several parallel projects, and summarize the design concept after detailed review and evaluation.
Part VI: Detailed design
Three groups of design teams composed of 12 junior students from the design department help complete the product design results.

3.2 Results Verification
30 design-background experts are invited to fill in the evaluation questionnaire for the design results. The evaluation scope of the design results is the good product design criteria proposed by this research, and the evaluation standards are (very poor, poor, fair, good, very good). At last, the evaluation results are established into a factor evaluation matrix R, and the importance weight of evaluation index is discussed and decided by three experts. Finally, the fuzzy comprehensive evaluation (FCE) is used to evaluate the design output to verify the effectiveness of the design mode. The detailed design is carried out according to the prior verification results (Lin & Hsiao, 2018).

4 Results and Discussion
The design pattern proposed in this research takes the LAMDA method of lean thinking as the main structure, supplemented by the MANDALA chart to explore the biological strategy and biological modeling of bionic objects, and then introduces the summarized bionic Mandala chart into the causal diagram of lean product development process, and endows the product function with bionic concept creativity. In addition, since traditional lean thinking does not evaluate the design results, and consumers’ preference for product design is
often fuzzy. Therefore, Fuzzy Comprehensive Evaluation (FCE) is used to evaluate the fuzzy attributes of the design results.

4.1 Design Concept
The three groups of students take the causal map (Figure 4.) (Figure 5.) (Figure 6.) drawn in this research as the reference basis of design conception to carry out product design and development.

Figure 4. Design 1- Causal map combined with the Mandala chart
Figure 5. Design 2: Causal map combined with the Mandala chart

Figure 6. Design 3: Causal map combined with the Mandala chart
4.2 Design Results

**Design outcome 1:**
This design is a new type of mosquito lamp trap, which mainly catches mosquitoes through physical principles and is harmless to the environment. The top of the product has a light that attracts mosquitoes to gather at the top, and the suction hole is as meticulous as the glandular hairs of the Sundew, so when the internal motor is running for vacuuming, the air passes through the tiny holes and columns on the top of the product to create a Venturi effect to enhance the suction power, and the mosquitoes close to the top of the product will be easily sucked in and caught. The overall product is quite light and different from the mosquito lamp traps commonly available. (Figure 7.)

![Figure 7. Design outcome 1](image)

**Design outcome 2:**
In this design, we adopted a sustainable design approach to reduce the quantity of components composing a product. Latching techniques were used to reduce fixed parts, thereby reducing the future manufacturing costs. The overall design style was simple. The bionic concept of Drosera indica Lin. was applied to coffee table design. For example, the radial skeletal structures resemble stems and leaves of Drosera indica Lin. and the top of the skeletal structures is as adhesive as the glandular hair of the plant, which can secure glass in contact with the glass surface. (Figure 8.)

![Figure 8. Design outcome 2](image)
Figure 8. Design outcome 2

Design outcome 3:
This design is a special wine glass rack designed for restaurants or bars, which takes the shape of the Sundew as the design object. As shown in the picture, after the analysis of the shape outline, it is found that the radial growth of the root of Sundews maintains a certain stability of the stem. Therefore, in the design stage, the radial shape is applied to the base of the wine glass rack, which is presented in a simple radial way to achieve the effect of the overall stability of the product. The stem is one of the most important parts to maintain the stability of the entire Sundew plant. Although the stem seems slender, it is actually quite tough, allowing the height of the whole plant to extend upwards, and highlight the structure of the leaf predator, so as to capture more insects to obtain the necessary nutrients for its growth. In this design, the slender glandular hairs and transparent spherical glandular fluid shape are adopted in the design of the wine rack, so that the goblet with the same characteristics becomes a part of the design. In addition, the glandular hairs of the Sundew are shorter above the leaf surface, and the length of the lower part is longer. Therefore, the general wine glass is planned to be placed above the product, while the goblet is arranged in the lower part. Two types of wine glasses are used to represent glandular hairs of two lengths. The glandular hairs of the Sundew are saturated bright red, which is an important tool to attract insects. The Sundew attracts insects, while in this design, an array of LED red lights are planned to shine on the common glass goblets on the upper row and the transparent glass goblets on the lower row, making the goblets slightly reflect bright red light and attracting the eyes of people in the bar. (Figure 9.)
4.3 Use FCE for Design Evaluation

In this study, we invited experts in the field of industrial design to select comparably important items from the iF DESIGN TALENT AWARD 2021 (Edition 01) evaluation criteria and served it as the indicators of this study to evaluate the design, and then make the important order on each item under evaluation which is served as the weight proportion for the indicator to evaluate the design (Table. 3). Each evaluation index of the design results is evaluated by 30 experts with industrial design backgrounds. The questionnaire experts group consisted of 17 men and 13 women, including 3 persons aged 21-30, 15 persons aged 31-40 and 12 persons aged 41 or above. There are 2 (6.7%) with college or junior college education level, 15 Masters (50%), 13 PhDs (43.3%), 2 (6.7%) people in the field of expertise for less than 5 years, 17 (56.7%) in the field of expertise for 6-10 years, 6 (20%) in the field of expertise for 11-15 years, and 5 (16.7%) in the field of expertise for more than 15 years.

Table 3. Evaluation criteria and Weight proportion in this study

<table>
<thead>
<tr>
<th>Code</th>
<th>Evaluation criteria</th>
<th>Weight proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Degree of innovation</td>
<td>0.50</td>
</tr>
<tr>
<td>A2</td>
<td>Use value and usability</td>
<td>0.20</td>
</tr>
<tr>
<td>A3</td>
<td>Aesthetic potential, spatial ambience</td>
<td>0.15</td>
</tr>
<tr>
<td>A4</td>
<td>Respect for the individual, justice + fairness, positive experience and fun</td>
<td>0.01</td>
</tr>
<tr>
<td>A5</td>
<td>Feasibility and ease of implementation</td>
<td>0.105</td>
</tr>
<tr>
<td>A6</td>
<td>Social responsibility, comfort and pleasure</td>
<td>0.035</td>
</tr>
</tbody>
</table>
The questionnaire is rated as very poor, poor, fair, good and very good, expressed as \( V = \{ V_1, V_2, V_3, V_4, V_5 \} \).

The calculation formula is as follows:

\[
\bar{B} = \bar{A} \cdot \bar{R} = (a_1, a_2, ..., a_m) \cdot \begin{pmatrix} \frac{r_{11}}{r_{m1}} & \cdots & \frac{r_{1n}}{r_{mn}} \end{pmatrix} = (b_1, b_2, ..., b_n), \quad b_j = \bigvee_{i=1}^{m} (a_i \land r_{ij}) \quad (j = 1, 2, ..., n). 
\]

Vector \( \bar{A} \) is the weight proportion of Evaluation criteria.

The three design results are analyzed and discussed as follows.

(1) Design outcome 1:

The factor evaluation matrix is as follows:

\[
\bar{R}_1 = \begin{bmatrix} 0 & 0 & 0 & 0.419 & 0.581 \\ 0 & 0 & 0.097 & 0.484 & 0.419 \\ 0 & 0 & 0 & 0.290 & 0.710 \\ 0 & 0 & 0.129 & 0.419 & 0.452 \\ 0 & 0 & 0.065 & 0.484 & 0.452 \\ 0 & 0 & 0.032 & 0.290 & 0.677 \end{bmatrix}
\]

According to the statistical results, 100% of the experts think that the design results are good or very good in the design requirements of “A1”; 90.3% of experts rated “A2” as good or very good; 100% of experts rated “A3” as good or very good; 87.1% of experts rated “A4” as good or very good; 93.6% of experts rated “A5” as good or very good and 96.7% of experts rated “A6” as good or very good.

Next is the FCE calculation:

\[
\bar{B}_1 = \begin{pmatrix} 0.50 & 0.20 & 0.15 & 0.01 & 0.105 & 0.035 \end{pmatrix} \cdot \begin{bmatrix} 0 & 0 & 0 & 0.419 & 0.581 \\ 0 & 0 & 0.097 & 0.484 & 0.419 \\ 0 & 0 & 0 & 0.290 & 0.710 \\ 0 & 0 & 0.129 & 0.419 & 0.452 \\ 0 & 0 & 0.065 & 0.484 & 0.452 \\ 0 & 0 & 0.032 & 0.290 & 0.677 \end{bmatrix} = \begin{pmatrix} 0 & 0 & 0.097 & 0.419 & 0.500 \end{pmatrix}
\]

The FCE vector (0 0 0.097 0.419 0.500) is standardized and the result is (0 0 0.095 0.412 0.492).

From the results, the first design was evaluated as very good at 49%, 41% as good, 10% as fair, 0% as bad, and 0% as very bad. From the perspective of maximum degree of membership, the experts’ evaluation of this design proposal reached the “very good” level.

(2) Design outcome 2:

The factor evaluation matrix is as follows:

\[
\bar{R}_2 = \begin{bmatrix} 0 & 0 & 0.097 & 0.516 & 0.387 \\ 0 & 0 & 0.032 & 0.258 & 0.710 \\ 0 & 0 & 0 & 0.419 & 0.581 \\ 0 & 0 & 0.065 & 0.419 & 0.516 \\ 0 & 0 & 0 & 0.194 & 0.806 \\ 0 & 0 & 0 & 0.387 & 0.613 \end{bmatrix}
\]
According to the statistical results, 90.3% of the experts think that the design results are good or very good in the design requirements of “A1”; 96.8% of experts rated “A2” as good or very good; 100% of experts rated “A3” as good or very good; 93.5% of experts rated “A4” as good or very good; 100% of experts rated “A5” as good or very good and 100% of experts rated “A6” as good or very good.

Next is the FCE calculation:

\[
\begin{bmatrix}
0 & 0 & 0.097 & 0.516 & 0.387 \\
0 & 0 & 0.032 & 0.258 & 0.710 \\
0 & 0 & 0 & 0.419 & 0.581 \\
0 & 0 & 0.065 & 0.419 & 0.516 \\
0 & 0 & 0 & 0.194 & 0.806 \\
0 & 0 & 0 & 0.387 & 0.613 \\
\end{bmatrix}
\]

\[
= (0\ 0\ 0.097\ 0.500\ 0.387)
\]

The FCE vector (0 0.097 0.500 0.387) is standardized and the result is (0 0.099 0.508 0.393).

From the results, the second design was evaluated as very good at 39%, 51% as good, 10% as fair, 0% as bad, and 0% as very bad. From the perspective of maximum degree of membership, the experts’ evaluation of this design proposal reached the “good” level.

(3) Design outcome 3:

The factor evaluation matrix is as follows:

\[
\begin{bmatrix}
0 & 0 & 0.065 & 0.581 & 0.355 \\
0 & 0 & 0.065 & 0.355 & 0.581 \\
0 & 0.032 & 0.097 & 0.419 & 0.452 \\
0 & 0 & 0.032 & 0.548 & 0.419 \\
0 & 0 & 0.065 & 0.613 & 0.323 \\
0 & 0 & 0.032 & 0.419 & 0.548 \\
\end{bmatrix}
\]

According to the statistical results, 93.6% of the experts think that the design results are good or very good in the design requirements of “A1”; 93.6% of experts rated “A2” as good or very good; 87.1% of experts rated “A3” as good or very good; 96.7% of experts rated “A4” as good or very good; 93.6% of experts rated “A5” as good or very good and 96.7% of experts rated “A6” as good or very good.

Next is the FCE calculation:

\[
\begin{bmatrix}
0 & 0 & 0.065 & 0.581 & 0.355 \\
0 & 0 & 0.065 & 0.355 & 0.581 \\
0 & 0.032 & 0.097 & 0.419 & 0.452 \\
0 & 0 & 0.032 & 0.548 & 0.419 \\
0 & 0 & 0.065 & 0.613 & 0.323 \\
0 & 0 & 0.032 & 0.419 & 0.548 \\
\end{bmatrix}
\]

\[
= (0\ 0.032\ 0.097\ 0.500\ 0.355)
\]

The FCE vector (0 0.032 0.097 0.500 0.355) is standardized and the result is (0 0.033 0.099 0.508 0.361).
From the results, the third design was evaluated as very good at 36%, 51% as good, 10% as fair, 3% as bad, and 0% as very bad. From the perspective of maximum degree of membership, the experts’ evaluation of this design proposal reached the “good” level.

5 Conclusion
In this research, three groups (12 students in total) of junior students from the design department are required to perform the LAMDA method of lean thinking, supplemented by the Mandala chart to explore the biological strategy and biological modeling of bionic objects, thus introduce the bionic Mandala chart into the causal map of the lean product development process, endow the product functions with the concept of bionic creativity, and evaluate the design results by fuzzy comprehensive evaluation. The experimental results show that the method proposed in this research can help students in the field of product design to implement and apply bionic design, help them quickly grasp the relationship between thinking mode and creative orientation, and help them achieve good product design evaluation, so as to improve the efficiency of product development.

References


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