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A product design based on interaction design and axiomatic design theory

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Abstract

With the development of technology, the improvement of living standards, personalized designs that emphasize diversity and self-fulfillment are becoming more and more popular. As a result, designers must focus more on user needs. Traditionally, most of designers only focus on satisfying users' functional needs and often ignore users' emotional and psychological needs. This paper presents a design method that combines interaction design with axiomatic design. The proposed method first employs interaction design to acquire user needs with respect to three aspects: "people", "products" and "environment" and then adopts axiomatic design to complete the conceptual design. The methodology is demonstrated and validated with a case study of children bicycle. The results show that the proposed method significantly enhances users' experience of the product and meets more comprehensive user needs, especially in terms of users' psychological and spiritual needs.

Keywords: Interaction design ,Axiomatic design; User needs

1. Introduction

With the increasing intensity of competition and establishment of buyer market, customer satisfaction has become one of the most important driven forces to succeed in the market. Personalized designs that emphasize diversity and self-fulfilment are becoming more and more popular. Designers pay more attention to user needs for products. The acquisition and conversion of user needs have become the focus of the design method study.

Many researches on needs mapping have been carried out. For example, Suh proposed Axiomatic Design (AD) theory in 1990 which realized the mapping of user requirements to product structures [1]. Shigeru Mizuno proposed Quality Function Deployment (QFD) which is a customer-driven product design method [2]. Selcuk Cebi et al applied AD and fuzzy sets theory into traditional product design method to analyse the relationships between functional requirements and design parameters [3]. Renbin Xiao et al established mathematical model to realize the automatic distribution of the product configuration based on the mapping of functional requirements to design parameters [4]. Lee applied the fuzzy goal programming technique into QFD to determine the importance degrees of various technical features which provide the basis of product improvements [5]. Ref [6] used QFD and Kano model to classify user needs, which can be transformed into a product's functional characteristics, in order to realize customer satisfactions. Wasserman et al combined the fuzzy sets theory with the TOPSIS to determine the degrees of user needs importance [7].

However, previous studies mainly focus on the mapping of user needs to products and little attention has been paid to how to acquire user needs exactly. Designers often define user needs directly or only focus on satisfying users' functional needs. So, the products may not meet comprehensive user needs, and user satisfaction may decline.

In response, interaction design is introduced to acquire user needs. Interaction Design is a new discipline and it was raised by Bill Moggridge in a design session in 1984. It concerns on understanding the target users' needs. Interaction system is composed of people, products and environment [8]. We can get user needs from these three perspectives.

This paper combines interaction design with AD. First, interaction design method is used to acquire user needs. Then,

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AD is used to the mapping of user needs to design elements of products. At last, a case study of children bicycle is presented to verify the effectiveness and feasibility of the proposed approach.

2. Model Construction for a product design

2.1 Construction of interactive system

In this section, how to acquire user needs by interaction design will be presented. The interaction design is characterized by not only studying users' own needs but also attempting to put users into the system of "people-environment-product ". In the following, three aspects of "people", "products" and "environment" will be studied.

(1) The study of people

First, we study user needs based on Maslow's hierarchy of needs theory. According to this theory, human needs can be divided into five levels, namely physical needs, safety and security needs, social acceptance needs, esteem needs and self-actualization needs as shown in Fig. 1 [9]. It requires designers to capture user needs from this five levels. It will be better for designers to capture users' high-level needs, such as esteem needs and self-actualization needs.

(2) The study of product

Many elements of products will exert influence on user needs. Only the ergonomics is studied in this paper since it plays a significant role in user needs. To be specific, it includes the following aspects:

1) Product design needs to be consistent with human body size parameters.

2) Products should be coordinated with human beings' physical and psychological state.

3) The use environment of the product should guarantee the health, safety and comfort of human beings.

(3) The study of environment

Different environments also affect user needs. For example, people from different social levels may have different characters, so their expectations on a product's performance also vary accordingly. People from different places such as wealthy city and poor mountain area may also favour different product performances.

People, product and environment are interactive and interdependent. For example, rich people may like famous brand products more. But poor people may like cost effective products more. Another example, for the products which will be usually used in home or office, people may pay more attention to them appearance to present their personality. However, if the product will be usually used in harsh environment, the durability will be the most important element which people consider. The typical model of interactive system is shown in Fig. 2.

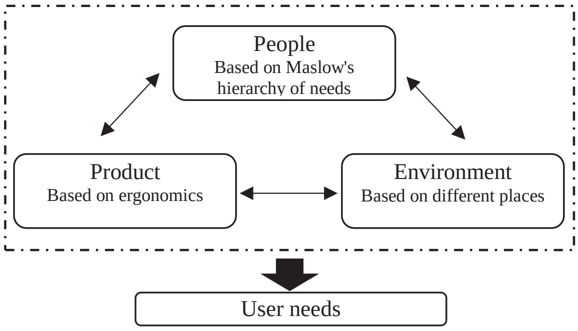

Fig 2. Typical model of interactive system

2.2 Axiomatic design based on interactive system

After getting user needs, how to map the user needs to product specifications by AD will be presented. Axiomatic design theory can be divided into four domains of customer, function, physical and process. Each domain has its own characteristics such as customer attributes, functional needs, design parameters, and process variables. Product design process is the conversion parameters between the two domains adjacent to each other in the process, as shown in Fig. 3 [10-12].

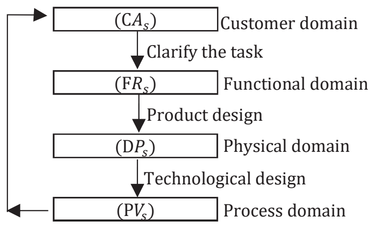

Fig 3. Conversion between four domains in axiomatic design

The validity of the design is guaranteed by two design axioms.

(1) Independence axiom: Maintain the independence of functional needs.

Mathematically, the relationship between FRs and DPs can be shown as follows:

$$\{FR\} = [A]\{DP\}$$

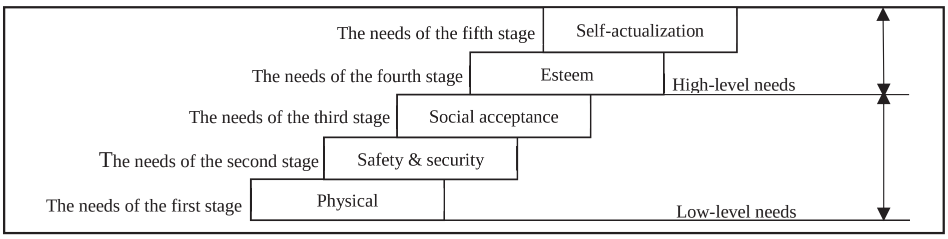

Fig 1. Maslow's hierarchy of needs

In the formula, [FR] is the vector of FRs, [DP] is the vector of DPs, and[A] is the matrix mapping DPs to FRs, effectively describing that DP is necessary for the FR.

If [A] is a diagonal matrix then the design is uncoupled. If [A] is triangular then the design is decoupled. Otherwise the design is coupled [13].

(2) Information axiom: Minimize the information content. Information content is defined as:

$$I = \log_2\left(\frac{1}{p}\right)$$

In the formula, p is the probability of the design parameters to meet the functional requirements.

After the using of interaction design and AD, final design elements will be got. The entire design concept of the design method paper is shown in Fig. 4.

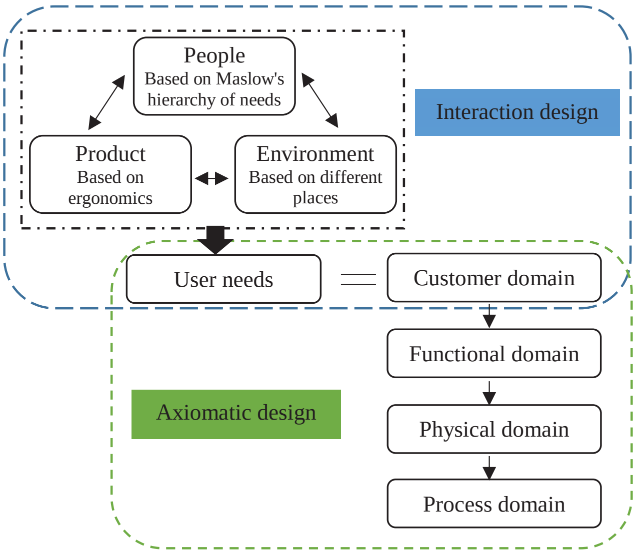

Fig 4. The entire design concept of the design method paper

3. Case study

To verify the effectiveness of the proposed approach, a children bicycle is designed in this part. About three years old Chinese children, living in city with their families of three members including their parents and themselves will be studied in this paper.

3.1 Construction of interactive system to get user needs

First, we will obtain the children needs by interaction design.

(1) In the aspect of "people", the key stakeholders include children themselves, their parents and government. Two research ways were adopted to acquire children and parents' needs. First, 23 children and their parents were interviewed face to face. Second, questionnaires were used and 67 valid ones were got. As for the government, relevant regulations for children's bicycles were examined. Finally, their needs were acquired and classified as follows:

For children, they just hope the bicycle can be easy to ride and comfortable. In the aspect of social acceptance needs, they hope the bicycle can attract the public attention at the first sight and can change appearances.

For parents, safety is the most important element for most parents. It's required that the materials of the bicycle are pollution-free and the bicycle should be portable. In the consideration of self-actualization needs, the bicycle is expected to have a certain cultural connotation and preferably educational function.

For the government, there are specific provisions for each part of the bicycle to make sure bicycle's safety, such as stability and strength of the handlebar part, surface of the pedal part and size of the seat part. Designers must obey these provisions. What's more, the bicycle should be environment-friendly.

(2) In the aspect of "product", the ergonomics theory is used to consider the user needs. Dimensions of the bicycle needs to be consistent with children body size. A Children bicycle consists of the following components, as shown in Fig. 5. According to the children body size which we get from the internet, the specific dimensions of the bicycle are obtained as shown in Fig. 6.

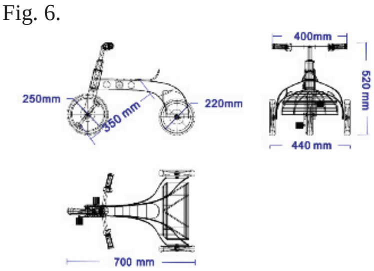

Fig 6. The dimension of the bicycle

(3) In the aspect of "environment", in this paper, children's families are featured by small population and simple family relations. Their parents may have little time to accompany them. They maybe lonelier and hungrier for more "playmates". So the bicycle should have the scenario imitation function to make children have more playmates to play with.

Above all, we get the user needs, as shown in Table. 1, based on Maslow's hierarchy of needs.

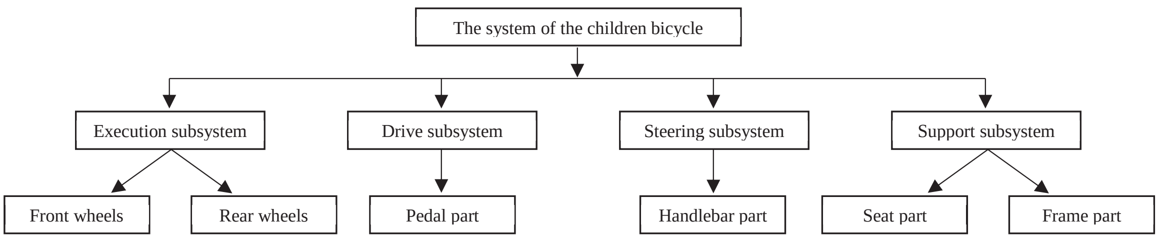

Fig 5. The system of the children bicycle

Table 1. User needs of the bicycle

Physical	Have basic riding function
	Meet the human-machine dimension
	Portable
Safety & security	Safe enough to ride
	Comfortable enough to ride
	The material is harmless, environmental protection
Social acceptance	Attract people's attention
	Several appearances
	Scenario imitation
Esteem	Approachable
	Interesting
Self-actualization	Have education

3.2 Get axiomatic design model according to CAs

In this section, how to map the user needs to a bicycle by AD will be presented. We just explore the social acceptance in Table. 1. The CAs of social acceptance needs are presented as follows.

CA_1—Attract people's attention

CA_2—Have several appearances

CA_3—Have scenario imitation

Then the functional requirements and design parameters are shown in Table. 2.

Table 2. Functional requirements and design parameters

FR	DP
FR_1—Make a sound	DP_1—Press the bottom
FR_2—Change the shape of the bicycle	DP_2—Arrange and combine the components of bicycle
FR_3—Imitate the scene of life	DP_3—Cosplay

Among them, design matrix of the FR_1, FR_3 is the diagonal, show as follows:

$$\begin{Bmatrix} FR_1 \\ FR_3 \end{Bmatrix} = \begin{pmatrix} X & 0 \\ 0 & X \end{pmatrix} \begin{Bmatrix} DP_1 \\ DP_3 \end{Bmatrix}$$

FR_2 was decomposed into low-level functional requirements. According to Fig. 4, the bicycle includes 6 parts. These parts all can be used to change the shape of the bicycle.

FR_{21}—Change the handlebar

FR_{22}—Change the frame part

FR_{23}—Change the pedal

FR_{24}—Change the front wheels

FR_{25}—Change the seat

FR_{26}—Change the rear wheels

In order to determine whether these functional requirements are beneficial or not, we should consider the actual scenario that children use the bicycle. With the consideration, we remove the last four parameters from the six FRs, and keep only the first two FRs.

FR_{21}—Change the handlebar

FR_{22}—Change the frame part

The following information was obtained after considering the physiological and psychological factors of children: (1) It is beneficial for children themselves to change the handlebars and the frame parts to improve their manual ability. (2) It is better to use a simple way to change the bicycle shape to meet the needs of children's self-development.

Above all, we get the following design parameters:

DP_{21}—Change the colour of the handlebar

FR_{22} needs to continue to be decomposed and specific design parameters are shown as follows in Table. 3.

Table 3. Specific design parameters

FR	DP
FR_{221}—Transform the patterns of the frame of the bicycle	DP_{221}—Rotate the front of the frame which is the second part of the bicycle in fig. 7
FR_{222}—Put different cards on the frame of the bicycle	DP_{222}—Set a small basket in front of the frame which is the third part of the bicycle in fig. 7
FR_{223}—Place different toys behind the frame of the bicycle	DP_{223}—Set a basket in the behind of the frame which is the fifth part of the bicycle in fig. 7

Design equation is shown as follows:

$$\begin{Bmatrix} FR_{221} \\ FR_{222} \\ FR_{223} \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_{221} \\ DP_{222} \\ DP_{223} \end{Bmatrix}$$

Through using the above models, final design elements are acquired and the bicycle is shown in Fig. 7.

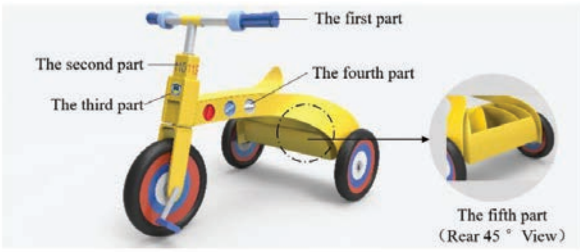

Fig 7. The final result

The bicycle is designed for playing games among children. By changing some parts of the bicycle, it can present three states including police cars, ambulances and fire engines. The analysis of design points is shown as follow:

The first part: the colour of the handlebar can be changed into blue, red and white colour to present the bicycle in different states.

The second part: for Chinese children, by rotating this part, the number on this part will change into "110", "120" and "119" to represent the police car, ambulance and fire engine respectively.

The third part: three different cards with badges can be put in this part by children themselves to exercise ability of permutations and combinations.

The fourth part: different colours are used to represent three different sounds. Pressing different button can make different sounds including police cars, ambulances and fire engines sounds respectively.

The fifth part: different toys to be applied in different scenarios are placed in three oversized bucket to provide children with a good environment for cosplay in different scenarios.

The evaluation of the program: In order to evaluate the bicycle, we compared the bicycle in this paper with that on the market which is shown in Fig. 8. On the basis of CNs, the children designers used three levels “Good”, ”General” and ”Bad” to evaluate and the conclusions were obtained in Table. 4.

Fig 8. The product on the market

Table 4. Conclusions of the evaluation

CNs	The product of this paper	The product on market
Have basic riding function	Good	Good
Meet the human-machine dimension	General	Good
Portable	Bad	Bad
Safe enough to ride	General	Good
Comfortable enough to ride	General	Good
The material is harmless, environmental protection	Good	Good
Attract people's attention	Good	Good
Several appearances	Good	General
Scenario simulation	Good	Bad
Approachable	General	General
Interesting	Good	General
Have education	Good	General

The result shows t the bicycle in this paper has 7 goods, 4 generals and 1 bad. The bicycle on market has 6 goods, 4 generals and 2 bads. It reveals that the bicycle in this paper meets the user more comprehensive needs, especially in high-level user needs such as the esteem and self-actualization.

4. Conclusion

In this paper, the study mainly concerns on how the designers accurately acquire the user needs, and then fast and effectively transform the needs into products. In order to improve interaction between users and products, a detailed construction of interactive system has been proposed to accurately obtain the user needs. Then axiomatic design was used to complete the entire production process.

An application of the proposed approach is illustrated with a children bicycle design. The result shows that it allows designers to accurately grasp the user needs and improve product experience in a fast and effective way. It’s expected that, by using interaction design, products can be designed more consisted with user expectations and used by users well and appropriately.

Acknowledgements

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