A Topological Variation-Oriented Approach for Enhancing Creativity in Education of Product Design

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Doctoral Dissertation

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Abstract

This thesis introduces an approach for aiming at promoting the effect of product design creativity by using topological properties variations. The study first proves that the visual perception of topological properties variations is useful for product innovation and second verifies the approach for product design creativity based on topological properties variations.

A primitive and general function of the visual system is the perception of global topological properties. People will give priority to directing their attention to the global topological properties of an object compared with the local geometric properties. If a variation of topological transformation occurs in the shape of a product, the product will receive more attention from customers, and opportunities will be gained to publicize the product's innovative points that cannot be perceived by vision, such as function, performance, experience, and so on. The hypothesis is that the perception of topological properties (holes, connectivity and inside/outside) exists in the shape of the product, and humans can pay attention to products that are relational to topological properties variations that have occurred in the shape. From the first experiment conducted in recognition of bicycles, we ascertained that people pay attention to bicycles with variations of topological transformation. The Repertory Grid Technique was used to discover and discriminate the reasons for such attention. We extracted the mental constructs of the participants for the products with topological properties variations and identified the reasons for innovations.

The topological variation – oriented approach for creativity generation (TVC) as a visualized sheet that evolved from a rich picture and showed the relationship between products and human was constructed through four territories: product, human, interaction, and experience. Each field is distributed in a vertical direction from left to right in a logical order of product, human, interaction, and experience. Each field is divided into several elements, and corresponding elements of each field are arranged in a horizontal direction. When topological properties variations occurred, certain new relationships arose in the elements and the novel products were generated strong possibility. In the second experiment, instruct the subjects to master TVC to design the chair. Subjects use this approach to get creative ideas that are significantly innovative. In this experiment, on the one hand, the subject's design ability was significantly improved after using TVC. On the other hand, testing TVC has advantages in some respects over the other approach that students are good at in product design. Finally, the

thesis discusses the contribution of the research to knowledge science and product design education.

From the perspective of knowledge science, TVC reveals the roots and evolution of creativity as a visual sheet, revealing that the root of creativity is to create new connections between things. In a narrow sense, TVC is a visual plane that can be applied to product design creativity. In a broad sense, TVC is a key to open the door to the study of the cognitive laws of new things, as well as the study of many psychological concepts. Creating new product design theories and methods is very important basic research work in universities. Topological visual perception is the fundamental and primitive functions of human beings vision system. The product form design theory and method developed from this basic visual perception feature is minimally influenced by regional culture and ideology and has a strong universality. It is suitable for the rapid globalization of the commodity market and can attract the attention of consumers to the greatest extent.

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Nomenclature

KS	Knowledge Science
NPD	New Product Development
PDE	Product Design Education
RGT	Repertory Grid Technique
RPs	Rich Pictures
SCAMPER	Substitute, Combine, Adapt, Magnify or Minify, Put to other uses, Eliminate or Elaborate and Rearrange or Reverse
SSM	Soft Systems Methodology
TVC	Topological Variations—Oriented Creativity Generation
TPV	Topological Properties and Variations

Chapter 1

Introduction

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Chapter 1. Introduction

1.1 Background

The success of a product is dependent on creating unique and superior product characteristics, as perceived by customers. Product design is a key driver of competitive advantage and new product success. Considered broadly, product design encompasses a range of engineering-related attributes including ergonomics, production efficiency, as well as recyclability, distribution ease, and aesthetics. However, recent work has noted the particular relevance of product form on product performance (Truong, Y et al., 2014). Product form referred to as product aesthetics or visual product appearance can help products stand out in cluttered markets by capturing consumers' attention and creating positive emotional reactions. Further, product form can generate desirable inferences regarding product attributes and thus have a positive effect on perceptions of product quality.

The discussions on product innovation and design thinking about existing methods are not uniform in scope or perspective. The method attempts to solve the problem to develop innovations based on consumer demands and comments in the fields of products, services, or other relevant tangible or intangible matters. Design Thinking bridges the gap between a designer's analytic approaches to solving problems. Its focus is consumer orientation and concrete problems of daily life and the improvement of particular shortcomings in products, services, or processes by innovative thinking.

In the existing product design method, focus on many characteristics of the product, such as appearance, usability, aesthetics and user experience. Some of these are the factors outside the person, controlled by designer and manufacturer, or by advertising and such things as brand image. And some come from within, from our own, private experiences. Generally, these characteristics can be summarized into three levels of design: visceral design, behavioral design, and reflective design (Norman, D. A. 2004).

Visceral design is about the initial impact of a product, about its appearance, touch, and feel.

Behavioral design is all about use. This is the aspect of designers in the usability community focus upon. There are four components of good behavioral design: function, understandability, usability, and physical feel.

Reflective design covers many territories. It is all about the message, about culture, and the meaning of a product or its use.

In this context of intelligent age, intelligent control has been applied in many kinds of products, and the form of products has changed dramatically(Waris, M. M et al., 2018). Thermometers range from mercury column displays to indoor temperatures that can be checked in the office through apps on mobile phones; from bicycle to segway, the number of wheels hasn't changed because of computer control, but the arrangement of wheels has changed dramatically, even subverting people's perception of balancing force. Energy, materials, and control are the core technologies of products at present. With their continuous innovation, the original logical structure of many products has been deconstructed and new logical relationships have been created. The bondage of manufacturing products is getting smaller and smaller, and the gap between creativity and manufacturing is gradually disappearing. Nowadays, with the bursting of new science and technology and the unprecedented degree of product innovation, new innovative thinking emerges in endlessly. By observing the innovation process of existing products, this study summarizes a set of product innovation thinking and methods from its form transformation.

1.2 Objective and scope of the Ph.D. project

The overall aim of this dissertation work can be summarized as: the method of idea generation based on topological properties variations is an effective tool for product design education. The topological properties variations in this study come from topological perception theory, that is, a human vision first perceives topological

properties, and graphs with topological differences are first perceived. The study divides two main experiments, the first experiment is to test that people can give priority to products with topological properties variations in shape. With this problem, we began to study human visual cognition and found that the visual cognitive activities advocated by topological visual cognition started from a wide range, and then to local features, which provided a favorable theoretical basis for finding the causes of the starting point problem. Typical morphological topological variations are selected from existing products. Through the first experiment, it is proved that the topological properties variations in product form can attract the attention of people. In the process of showing the existing product innovation ideas with a visualized sheet which operating topological properties variations. And when the visualized sheet is applied to the products without topological properties variations in their shapes, they also happened to the variations on their visualized sheets. Therefore, a hypothesis is proposed: the visualized sheet can significantly improve the design capabilities of students in product design. In the second experiment, not only test the hypothesis but also verified the sheet as a method of product design has certain advantages in some aspects compared with other design methods and can be applied to product design education.

The objective of this study is to build a method based on the topological properties variations of visual perception. It issues from the automatic, prewired layer, called the visceral levels of the brain. The visceral level makes rapid judgments of what is novel appearance or a traditional one, and sends appropriate signals to the motor system and alerts the rest of the brain. This is the start of affective, cognitive processing. Therefore, TPV is a universal method of product innovation for designers and has universality for users. For designers, this model is easier to master and apply to design. On the other hand, it is not limited by the personal experience of users, cultural background, and other factors, and can intuitively perceive product innovation.

This study includes the following academic fields: products innovation, visual attention, visual topological perception, repertory grid technique, and rich picture. TVC

is deduced gradually from these academic fields and forms a method for idea generation of product design, the thinking process is represented by specific graphical symbols.

1.3 Organization of this Ph.D. work

This Ph.D. work has been performed in two main parts, shown as Figure1:

1. Topological perception of attention to product shape, as the research start of visual perception on product shapes;

2. The approach of creativity generation based on topological variations.

The first part of the research starting point comes from everyday phenomena. There are many reasons for this phenomenon. The author found the theory of topological visual cognition and realized that it seems that this theory can be applied to product form creativity activities. The attention caused by the topological variations of product shape is superior to that caused by other types of creativity. Therefore, a set of experiments was designed to verify the hypotheses. After proving the first hypothesis, the author finds that the visualized sheet can present the process of product design creativity. Whenever the visualized sheet happens to topological variations, obvious creativity will occur in products, and this creativity is very novel. Next, the author designed a set of experiments to verify that the design students can get a greater degree of creative idea generation, and these ideas can be widely recognized.

This dissertation report is organized as follow. In Chapter 2 a literature review of topology, topological properties, and variations of topological transformation, visual system and topological visual perception, attention and product innovation, and topological perception in the shape of the product. Chapter 3 describes the case study impact of topological perception on attention to product shape. Chapter 4 illustrates the case study the method of creativity generation based on topological variations. In Chapter 5, an overview of the two cases studies analysis and results. Chapter 6 discussed focusing on the findings and analysis, contribution to product design. Finally, in Chapter 7 summary and conclusions are drawn.

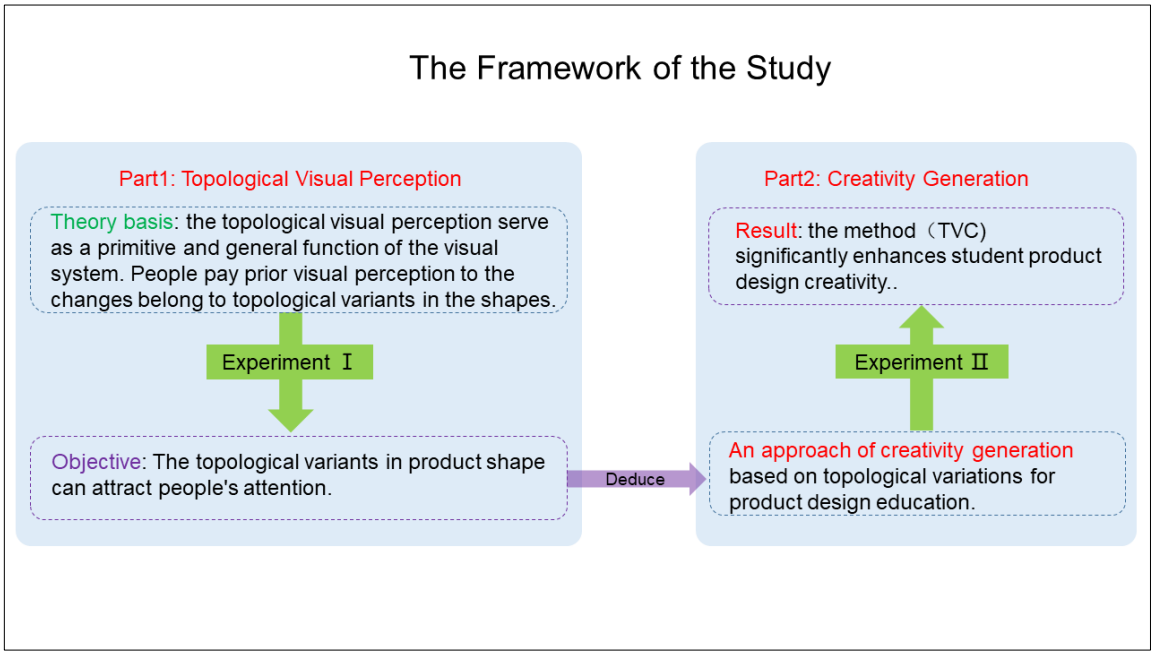


Figure 1 The framework of the study

Chapter 2

Literature review

Content

Chapter 2. Literature review

2.1 Existing innovative methods for product

Design as a term, in general, includes various design fields such as product design, graphic design, communication design, and design in engineering. Product design involves more knowledge. Designers use to navigate divergent and convergent thinking and create new possibilities through design thinking toolkit. As far as the current design methods are concerned, there are some based on the design itself (Baxter, M., 1995), and some focus on business management (Liedtka, J et al., 2011). By synthesizing various documents and materials, the methods summarized below are mainly limited to the common design methods in the creative stage in the early stage of product design. The methods summarized below are mainly limited to the common design methods in the creative stage in the early stages of product design. These methods are taught in the professional courses of the department of product design of Dalian Polytechnic University (DPU). The subjects of the second experiment were mainly students of the Department of Product Design of DPU.

1. Visualization

Design thinking includes the interaction among perceptual, intellectual and rational levels. Sensibility is the basis for the existence of sensory intuition, which is related to the theories of aesthetics, semiotics, and hermeneutics; intellectuality is the further synthesis of sensory intuition materials based on pure concepts and categories, including empiricism, structuralism, post-modernism and other knowledge; rationality is the use of reasoning for logical thinking, with reality. Practical and speculative characteristics, all principles form objective validity within the scope of experience and relate knowledge of psychology, sociology, management (Cross, N. 2011). Visual thinking is an important feature of design thinking. Visual expression with the effect of "simplifying complexity into simplicity" itself also relates to three levels of design

thinking (Leake, J. M et al., 2013). Furthermore, the process of thinking is controlled by the visualization, so different creative thinking is formed corresponding to the method, that is, imagination, intuition, control experiment, and formalization. The visual trend of design thinking is the typical form of creative thinking. The application of information visualization in the field of knowledge management is to trigger the cognitive process of "vision-mind-image thinking-innovation". The creativity of products needs to be transformed and designed through knowledge, not only the accumulation of creativity and culture but also the consideration of social psychology and the market mechanism. Using imagery to envision possibilities and bring them to life (Pedell, S et al., 2005, September). Graphically express the possibilities of the future. At this time, participants should not be limited by the performance of painting, and draw their own ideas as soon as possible in a relaxed state.

2. Journey Mapping

Assessing the existing experience through the customer's eyes. Journey Mapping is one of the most useful tools in the toolkit of designers. Designer traces a customer's “journey” as a series of steps involved in an experience. He or she gains a deeper understanding of employees' work routines when map a customer's journey in the redesign of internal processes (Howard, T., 2014).

Inspired by user research, there will not be two identical user experience maps in the world. Regardless of the format, they allow the team to consider the interaction experience from the point of view of users rather than from the inside out. They are tools that can help teams evolve from a primitive trading model to a long-term customer relationship based on respect, consistency, and trust. All teams have business goals so that user experience maps can be used as a support component of team members' social experience so that users can be at the forefront of system design decisions (Norton, D. W et al., 2013). They can be used in the current and future state, can be used to study the outstanding pain points of the current society, can also expose major opportunities, all in order to create a better experience for users. Use this map to gain internal

consensus among users, such as how users from different channels should be treated. Even members who have never cooperated and communicated with each other in different fields before contributing extraordinary value to this large team. Drawing or describing the way the user experience is used across domains enables all stakeholders in all areas of the enterprise to better understand the essence of the whole experience from the user's perspective. What do they want to say, what do they think, feel, see, hear and do? User experience maps can help us explore whether assumptions in the design process really hold (Rosenbaum, M. S et al., 2017).

3. Mind Mapping

Mind mapping method refers to generating insights from exploration activities and using those to create design criteria. It is a popular all-brain learning method, which can present various ideas, ideas and their correlations in an image-based visual scene. It can organize some core concepts, things and other concepts, and image concepts of things, and input the memory treemap in our brain. It allows us to organize and process complex concepts, information, and data in a more vivid and understandable form.

The application of mind mapping is an effective way to describe the envisaged project methodology system (Edwards, S et al., 2010). It draws a frame on paper or conceives in mind first, then extends to all areas of the organization for comprehensive consideration. The whole system can be designed in this way.

Let's take a look at the process of thinking, which is consistent with the way in which methodological systems are constructed. If a process cannot be delineated, it is useless. However, the human brain is so developed that mind mapping can be used to guide the development of methodological systems. In the process of thinking, your brain initially encounters biochemical or electromagnetic resistance, which hinders your thinking — just like clearing roads in the forest. The first was a strenuous effort as if you had to travel through the jungle. The second time, since the road was cleared up last time, it was not so difficult to walk. Frequent repetition makes it easier to deal with events. Similarly, creating profiles and recording them in creative graphical

formats can assist the human brain to receive, maintain, analyze and control output. What happens in the brain when people try to design project methodologies? The answer may be simple or extremely complex. Each trend of thought or transient information enters the brain — experience and memory (templates, codes, vocabulary) can be represented as a central sphere that emits ten, one hundred, one thousand, millions of hooks — they represent interconnections — with its own connections and relationships in turn. The number of associations can be understood as adult memories or databases, and when these words are needed, it ensures that the brain is like an analytical supercomputer, which is more advanced than many advanced computers in the world.

4. Brainstorming

Generating new possibilities and new alternative business models. This method is mainly discussed by the staff of the Value Engineering Working Group in a normal and unconstrained atmosphere of the form of the meeting, breaking the routine, thinking positively, freely and fully express their views. (Dugosh, K. L et al., 2000). In group decision-making, due to the psychological interaction of group members, it is easy to yield to the authority or majority opinions, forming the so-called "group thinking". Group thinking weakens the group's critical spirit and creativity and impairs the quality of decision-making. To ensure the creation of group decision-making and improve the quality of decision-making, a series of methods to improve group decision-making has been developed in management. Brainstorming method is a typical one.

Brainstorming is based on two principles and four rules:

The first principle is to postpone judgment. Osborn believes that the human brain has two dimensions: critical thinking and creative thinking (Osborn, A., 2013). The purpose of delayed judgment is to keep the creative thinking part of the brain free from the interference of critical thinking. So let's first think about ideas and then evaluate them.

The second principle is that quantity is greater than quality. The logic behind this

principle is that the more ideas you think about, the more likely it is that one of them will become a solution to the problem.

Four rules governing brainstorming are:

(1) Criticism is not allowed. This is the most important rule. Only after all the ideas have been thought out can evaluation begin, otherwise the principle of "delayed criticism" can not be changed.

(2) Free speech is encouraged. The aim of this rule is to enable all problem-solvers to express their ideas quickly without fear that others will comment on them immediately.

(3) Quantity is the goal. The more ideas are put forward, the solution is clearer.

(4) Seek possibilities for merging and promoting ideas. The purpose of this rule is to encourage people to think of additional and better ideas based on other people's ideas.

5. Problem abstraction

Problem abstraction concise problems to most basic elements and then set problem goals and boundaries (Gregor, S et al., 2013). A simple statement of the problem as the beginning of the procedure for problem abstraction. If you want to solve this particular problem and then ask ‘why.’ The answer is then challenged with further ‘why’ questions until your ultimate objective is reached. The process for exploring and expanding a problem, its value is that each level of abstraction reveals new potential solutions.

Problem abstraction is aimed at systematically raising questions. In the process of answering questions, various ideas of solving problems may arise, which can make the information needed in design more sufficient and the solution more perfect.

6. Orthographic analysis

The orthographic analysis is a way of visualizing one, two or three attributes of a problem as a graphical representation, correspondingly one, two, or three dimensions. This presentation of problem attributes visualizing solutions through different combinations of attributes, or by expanding the problem in any of the given dimensions (Cooper, L. A., 1990).

The orthogonal analysis was used to extract the design elements of the product, and a solid model was established to present the design elements in three-dimensional vision. Secondly, the orthogonal experiment method is used to minimize the number and similarity of samples to be evaluated and to avoid the evaluation distortion caused by over-evaluation. Thirdly, the relative evaluation method is used to visually reflect the design differences and avoid the defect of low absolute evaluation sensitivity. Orthogonal analysis can determine that each design element has significant improvement space in one aspect, and can deduce the factors affecting user behavior and their importance. Orthogonal analysis method can effectively reduce the experimental process and data volume, and the conclusions can accurately present the evaluation results of the design. It is an effective and practical method to evaluate the design elements.

7. SCAMPER

SCAMPER is an acronym and stands for 'Substitute, Combine, Adapt, Magnify or Minify, Put to other uses, Eliminate or Elaborate and Rearrange or Reverse.' These headings show possible product modifications for stimulating ideas (Serrat, O., 2017). This approach allows designers to avoid focusing on one obvious one without thinking about others in a holistic way in the process of product modifications.

SCAMPER is similar to twelve ways of thinking (Li, S et al., 2017).

(1) Consider what you can add to this? Do you need to add more time or times? Can you make it higher and thicker? What's the result of combining this with other things? How about gathering suggestions, holding seminars and brainstorming?

(2) Consider what you can subtract from this? Can you reduce the time or number of times? Can you lower it a little and lighten it a little? What can be omitted?

(3) Consider enlarging this thing. What about expanding it? Can you increase the speed by lengthening and strengthening?

(4) Consider compressing this thing. What about shrinking it? Can we take down some, thinner, lower, shorter, lighter, and slice it down?

(5) What about changing shape, color, movement, model, and posture? What happens if we change the order?

(6) What are the drawbacks of this thing? What other shortcomings need to be improved? Does it bring inconvenience and trouble to people when it is used? Are there any solutions to these problems? Can this thing be used for other purposes? Or keep the status quo and make a slight change?

(7) What is the relationship between the result of something and its cause? Can we find a way to solve the problem? Can linking something or something help us achieve our goals?

(8) What things and situations can you imitate and learn by yourself? What is the result of imitating its shape, structure, and function? What is the result of learning its principle and technology?

(9) Can this replace another thing? If you use other materials, parts, the method is not good? Can I change my work, use other power, change my structure and change my timbre? Can we change the elements, model, layout, order, and schedule?

(10) Is there any other use in moving this thing elsewhere? Can this idea, truth, and technology be used elsewhere? Can you hear opinions and suggestions from other places? Can we borrow the wisdom of others?

(11) If we subvert this thing, the pros, and cons of a thing, from top to bottom, from left to right, from front to back, from inside to outside, what will happen? Many inventions in the world are inspired by reverse thinking.

(12) In order to solve a problem or improve something, in order to improve learning, work efficiency and prevent possible accidents or omissions, what needs to be stipulated?

8. Analogy

The analogy is a basic way of cognition, which is realized by treating one thing as another. That is to say, to find common ground between things A and B, to find the unknown features implied in things B, and to have a new understanding of things A,

which is different from the usual ones. The analogy can also be divided into attribute analogy and relational analogy. The former is based on specific values such as shape, color, weight, and size. If one thing is compared to another, it is mainly shown in the design as the similarity of morphological relationship, while the latter is based on a certain relationship and mostly embodied in a functional relationship (Hey, J et al., 2008). In the process of diffusive design thinking, the analogy is an important thinking activity and mean to improve the originality of design (Kalogerakis, K et al., 2010). Many wonderful ideas in artistic design creativity are realized using this ability of imagination and association.

9. Cliches and proverbs

Cliches and proverbs can help designers subvert stereotyped ideas. In this interesting way, designers break the logic of design thinking and let the very perceptual thinking enter design thinking (Proctor, T., 2010). Cliches and proverbs have a certain sense of the picture, the meaning is easy to understand, but the truth is profound. So this attribute has similarities in designing activities (Schank, R. C., 1988). The design has been pursuing concise form and striving for rich content.

By using proverbs as a medium, the logic contained in them, which has been well known by people, will combine seemingly unrelated and completely different elements of knowledge. Through this method, we can absorb high-quality creative ideas. This method should follow the two basic principles of "heterogeneous assimilation" and "homogeneous alienation".

Heterogeneous assimilation. It is the process of "changing strangeness into familiarity". It is a way of thinking that tries to connect the things you first come into contact with or the new discoveries to the things you already know. Look at the unfamiliar things as mature and familiar things, understand the unfamiliar things from familiar viewpoints and perspectives, think that the unfamiliar things have the same nature, function, structure, use and so on as familiar things, so as to familiarize the unfamiliar things, turn the unfamiliar problems into familiar problems, and get creative

ideas about new things.

Homogeneity and alienation. It is the process of "becoming familiar to strangers". It finds out the heterogeneous viewpoints in the things it is very familiar with through new insights. It is to look at familiar things with unfamiliar eyes, to observe known things with completely different viewpoints and perspectives from the past, to find out the new nature, new uses, new functions, new structures, new combinations of known things, etc.

10. Evaluation-PIPS.

A technique for doing this is called PIPS, the full name is phases of integrated problem-solving. Problem-solving should never be a one-off activity. It is on-going, tackling new problems as they arise. We need to develop and customize problem-solving techniques to suit both the organization and the people involved and to do so. The evaluation and feedback from each problem-solving activity are needed. The problem-solving process was divided into stages and looked at each individually by PIPS. PIPS divides the problem-solving activities into the tasks and processes involves. Designers evaluate the series of tasks and processes within each phase of problem-solving by scoring, on a 1 to 5 scale (Morris, W. C et al., 1978).

The purpose of this study is to create a topological variation-oriented approach to creativity generation from topological visual perception theory. But in order to understand the theory of topological visual perception more clearly, we must first study the mathematical basis of this theory.

2.2 Topology

Topology is a subject that studies some properties of geometric figures or spaces that remain unchanged after changing shape continuously (Rashevsky, N., 1954). It only considers the position relationship between objects without considering their shape and size (Munkres, J., 2014). Topology was the earliest related subject to study similar topography and landform. Geometric topology is a branch of mathematics formed in

the nineteenth century. It belongs to the category of geometry. Some contents about topology appeared as early as the eighteenth century. Some isolated problems discovered at that time played an important role in the formation of topology in the future. Topology is a branch of geometry, but it is different from plane geometry and solid geometry. Generally, the object of plane geometry or solid geometry is the position relationship between points, lines and planes and their metric properties. Topology has nothing to do with the measurement properties and quantity of the object of studies, such as length, size, area, and volume (Darke, I., 1982). After the establishment of topology, because of the development needs of other mathematical disciplines, it has also developed rapidly. Especially after Riemann founded Riemann geometry (Jost, J., 2008), he took the concept of topology as the basis of analytic function theory, which further promoted the development of topology.

Since the twentieth century, set theory has been introduced into topology, which has opened up a new face for topology. The study of topology becomes the corresponding concept of any set of points. Some problems that need to be described accurately in topology can be discussed by using sets (Kuratowski, K., 2014). Topology is a structure on a set.

Set theory is a branch of mathematics that studies the structure, operation, and properties of sets. The most important basic theory of modern mathematics was founded by Cantor in the 1870s and 1880s (Hausdorff, F., 2005). A set consisting of points on a plane (or space) is called a "point set." A set of points can be some isolated points or all points on a curve or in a region (Aczel, P., 2006). We can regard all kinds of geometric figures as a set of points, and then study the common characteristics of the points it contains in the relation of location and quantity so that we can often get more profound conclusions than intuition. The basic theory of point set is called point set theory, and the discussion of set theory is broader and more abstract than that of the point set. From the viewpoint of modern mathematics, the research object of each branch of mathematics is either a set with a specific structure, such as group, ring, topological

space, or can be defined by a set (such as natural number, real number, function). In this sense, set theory can be said to be the basis of modern mathematics. Set theory is a mathematical theory about infinite sets and infinite numbers. Set, as one of the most primitive concepts in mathematics, usually refers to the totality of things combined according to certain characteristics of laws. For example, the totality of natural numbers and the totality of points on a straight line (Egenhofer, M. J et al., 1991).

Point set topology is a mathematical discipline that studies the spatial structure of topology and the properties of mappings defined on it. It is not only closely related to many branches of mathematics but also widely used (Singer, I. M., 1967). Therefore, it is of great theoretical value and practical significance to study the history of point-set topology.

In 1874, Cantor published a proof entitled "On a Property of the Collection of All Real Algebraic Numbers" (Enderton, H. B., 1977). In this paper, the concept of countable sets is proposed, and the infinite sets are classified according to the one-to-one correspondence criterion. The following important results are proved:

(1) all algebraic numbers are countable;

(2) real numbers on any finite line segment are countable;

(3) transcendental numbers are countless;

(4) all infinite sets are not countable, and infinite sets also have numbers (cardinals) like infinite sets. The difference between them.

On January 5, 1874, Cantor asked the following question: Can a surface (such as a square with boundaries) be deliberately mapped to a line (such as a line segment with endpoints) so that each point on the surface corresponds to one point on the line and vice versa? The answer to this question is yes, although for several years he has thought the answer is No. After the publication of the papers on this achievement, people were attracted to study the nature of the metric space dimension. A number of papers appeared soon, which marked the beginning of set topology.

Topology is an important part of modern mathematics, and at the same time, it is an

ideological method that permeates the whole of modern mathematics. The term topology is transliterated from German "topologie" and was first introduced by Johann Benedict Listing in the 19th century to represent a new research direction, "Geometry of Location". Topology is concerned with spatial properties that are preserved under one-to-one, continuous transformations, such as stretching and bending, but not breaking or fusing. Important topological properties include connectedness and compactness (Zhuo, Y., et al. 2003). Hence, solid figures such a cube and a tetrahedron are topologically equivalent, because one can be transformed into the other through continuous transformations. An attribute of an object is called topologically invariant if it does not change under a continuous transformation.

2.3 Topological properties and variations

Topology is a science of spatial relations, regardless of area differences. According to the point of view of topology, a drop of water is exactly the same as the earth. Topology studies the properties of shapes, especially those that have been twisted, stretched or deformed. There is a mathematical term for this series of possible transformations, called continuous transformation, which roughly refers to "stretching change, not tearing or merging." For example, a circle may be stretched to an oval or hand-like shape, but we cannot dig a hole in the middle to make it a doughnut-like shape. Tearing and merging can cause discontinuity, so they are not allowed in topological deformation.

2.3.1 Topological properties

Topological properties concern both individual characteristics of an object (e.g., dimension, number of connected components) and relations among all objects of the scene. Topological properties do not change after topological transformations, such as rotation, translation, scaling, and rubber sheeting. If two different spaces have the same

topological properties, they are topologically equivalent. Formal criteria to establish topological equivalence are extremely important both for recognizing a particular configuration of objects and for checking if space has been transformed consistently. We illustrate the topological invariant by taking the geometric graph in the following example after the continuous change and some properties remain unchanged. The object of topological research is that a graph completely coincides with another graph after the topological transformation. In the process of transformation, the graph remains unchanged (Zhang, B., 1987). It attributes to the following two points:

1. Any point on the original graphΦcorresponds to the unique point on the transformed graph Φ_1, Mutual Single Value Correspondence;

2. The infinite adjacent points on the original graph Φ is also infinite adjacent points on the transformed graph Φ_1 - corresponding to each other continuously.

Mutual singular values and mutual continuity are the only conditions to be observed in topological transformation. The topological equivalence or homeomorphism of two graphs is to make one of the two graphs equal to the other after elastic deformation. Thus, the following geometric elements are topologically equivalent:

1. Circumference with simple closed curve and polygonal line. These lines can be planar or spatial;

2. Lines and simple unclosed curves and unclosed polygonal lines;

3. Spherical and various polyhedral and ellipsoid, oval and other closed surfaces;

4. Circular planes and hemispheres, cones, paraboloids, and other unclosed surfaces;

5. Ruled Surface and Unclosed Curved Surface.

It should be noted that only when two graphs are topologically equivalent or homeomorphic could one graph be transformed into another. As shown in Figure 2 (a), a revolving surface is topologically transformed into a straight cone by the corresponding line in the vertical direction (the straight cone is a projection surface whose horizontal projection coincides with the horizontal projection of the revolving surface). Figure 2 (b) is a square pyramid, which can transform topologically into a

straight cone. Because their axes or centerlines are used as "line light sources" and conical (or pyramidal) surfaces are used as projection planes, projecting along the direction perpendicular to the line light sources. A point on a pyramid is uniquely corresponding to a point on a cone. The (a) and (b) in Figure 3 are not topologically equivalent. Therefore, from (a) [or (b)] cannot be transformed into (b) [or by (a)]. When a cone is truncated into a circular mesa, for example, Figure 3 (c), a cylinder (b) and a mesa (c) are topologically equivalent. That is to say, in the topological transformation, if two graphs have different embryos, they can be transformed into homeomorphism using cutting and supplementing.

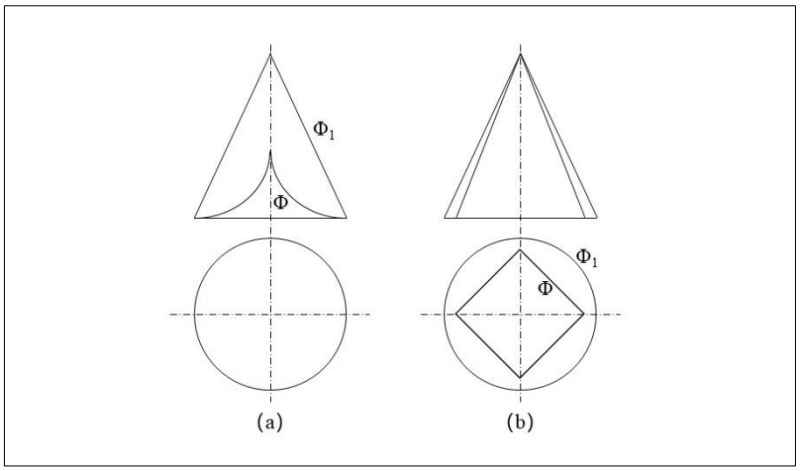


Figure 2 Topological properties of homeomorphic

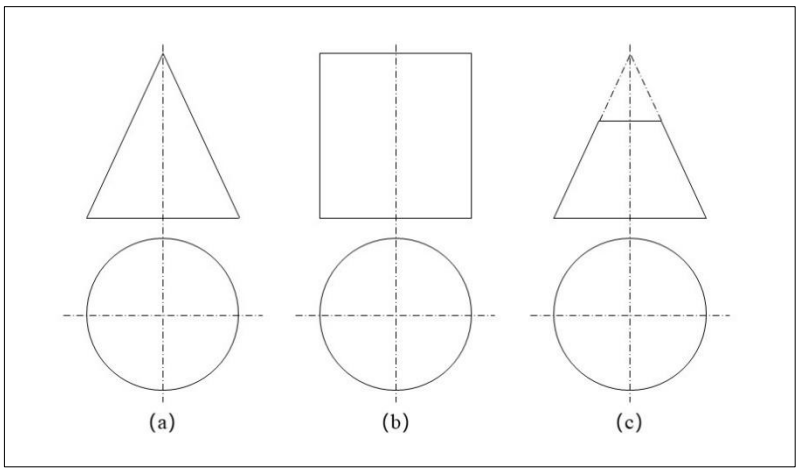


Figure 3 Topological properties of different topological equivalent

Since only two conditions are required for topological transformation: single value correspondence and continuous correspondence, a graph can be arbitrarily transformed into any graph equivalent to this topology. Therefore, the means of topological

transformation are very flexible and random. But in geometric transformation, to make the drawing follow regularly, it is usually necessary to make some additional provisions on the means of transformation, such as:

1. Projection methods - parallel, central, affine or curved;

2. Projection Surface - Plane, Cylindrical, Conical, Spherical or Arbitrary Surface;

3. Process - can be completed at one time or multiple times;

4. Graphical properties of transformations - can be linear sets, circular sets or combinations of various curves.

According to these rules, the following different methods of topological transformation (Wang Jinggeng., 2001):

1. Topological transformation using parallel projection;

2. Using affine corresponding topological transformation;

3. Topological transformation using graphic properties;

4. Topological transformation using central projection;

5. Topological transformation using parallel and central projection;

6. Topological transformation using two-center projection;

7. Topological transformation using refraction and reflection.

2.3.2 Variations of topological continuous transformation

If two objects have different topological properties, they must be different homeomorphisms. One of the most common topological properties is the Euler characteristic, named after the 18th-century German mathematician Leonhard Euler, which is commonly denoted by χ and conventionally defined for the surfaces of a polyhedron as $\chi = V - E + F$, where V, E, and F are the numbers of vertices (corners), edges, and faces in the polyhedron, respectively. For example, the surface of a convex polyhedron has Euler characteristic $\chi = V - E + F = 2$. On the other hand, several human-made goods are homeomorphic to either spheres or rings and can be molded forming

tiles. The topological transformations can be pictured as distorting a rubber sheet without creating holes or fusing edges. The Euler characteristics of a sphere and a ring (i.e., torus) are 2 and 0, respectively.

If we understand how adding an edge or vertex changes, we can easily understand why the Euler characteristic is conservative. A line between two vertices can add an edge, and then divide a face into two parts, adding one edge and one face, while the number of vertices does not change, so the value of F+V-E does not change. Similarly, adding a vertex to an edge, dividing the edge into two ends, adding one vertex and one edge, while the number of faces remains unchanged, so the value of F+V-E remains unchanged. Now let's block the surface of a circular object and count the values of F, V and E. We will find that its Euler sign is 0. The following figure is an example. If an object has two rings, its Euler's sign is - 2, there are three rings, and its Euler's sign is - 4 if we make a hole in an object, the Euler's sign of the object will be reduced by 2, shown in Figure 4.

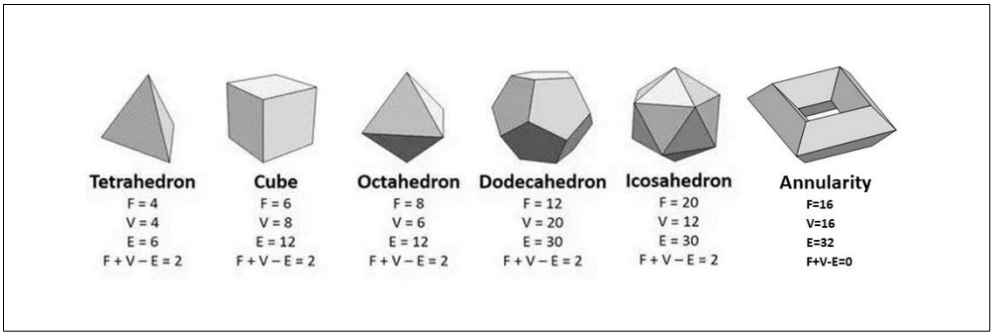


Figure 4 Euler characteristics of the polyhedron

2.4 Visual perception and topological properties

2.4.1 Visual perception

Vision is a physiological word. Light acts on the visual organs to excite the sensory cells, whose information is processed by the visual nervous system to produce vision. Through vision, people and animals perceive the size, shape, color, movement of

external objects, and obtain all kinds of information which is important for the survival of the body (Aloimonos, J et al., 1988). At least 80 percent of the external information is obtained by vision. Vision is the most important feeling of human and animals. Vision is the subjective sensation obtained by the peripheral sensory organs of the visual system receiving electromagnetic stimulation within a certain wavelength range in the external environment and coding and processing and analysis of the relevant parts of the central nervous system. The human eye can be divided into two parts: the retina of photoreceptor cells and the refractive system. The appropriate stimulus is the electromagnetic wave with a wavelength of 370-740 nanometers, i.e. the visible part, about 150 colors. This part of the light is imaged on the retina through the refractive system and is transmitted to the visual center of the brain through the optic nerve (Goodale, M. A et al., 1992). The color and brightness of the object can be distinguished. So we can see the outline, shape, size, color, distance and surface details of the luminous or reflective objects in the visual range.

The visual perception activities of people are very complex, and the research on visual perception has accumulated a lot of research results since ancient times. The most enlightening visual perception research for this study should be the Gestalt Visual Perception Theory (Koffka, K., 2013 et al; 1988). Gestalt visual perception theory is an experimental method to study human visual cognitive law and find many important visual laws.

1. From part to whole

When people try to identify an object, they first try to identify its rough outline, and then search and match the shape and object they already know from the brain. Only when all of them appear, our brain will carry out related patterning activities, which is a process of forming complex patterns from simple patterns (Quinn, P. C et al., 1993). In the process of product design, designers first use their common sense to determine the elements. Compared with a detailed object, a simple and clear object will communicate more quickly and the outline will be easy to debate.

2. Favor simple things

People usually like things that are simple, clear and orderly. Because for our instincts, these are things that are easier to understand, that is to say, things that we are more inclined to understand. So people want to spend less time dealing with and facing the current complex and uncertain things. When faced with complex shapes, people tend to reorganize into a simpler component or a simpler whole (Todorovic, D., 2008).

3. Concern about symmetry and order

People tend to accept shapes that are symmetrical around the center. Symmetry provides a sense of firmness and order (Zabrodsky, H et al., 2002). Human nature imposes order on chaotic situations, and this principle leads to the desire to maintain balance in a series of elements, even if complete symmetry is not required to maintain balance in this series of elements. Because people's eyeballs will find symmetry and order between each other more quickly and preferentially, these principles can be used to transmit information more quickly and effectively.

4. Distinguishing graphics and background

Graphics and background refer to the relationship between the main elements and negative space. The eyes separate the background and the graphics. Elements are seen as focus elements in the diagram, while the background is ignored (Graham, L., 2008). In a relatively stable environment, designers can better highlight the desired elements by using area and bump. For two overlapping shapes, smaller areas are considered graphics and larger ones are considered the background. Protrusions are often considered elements, while concave parts are considered the background.

5. Influenced by past experience

Observers often perceive things based on past experience. Past experience may be the most unreliable principle. But when combined with other principles, they also affect the principles of past experience (Brownell, P., 2010). Past experience is also a unique individual, so it is considered the most difficult to assume. But there are similarities in common experiences. Many of our common experiences often come from culture, but

different experiences absolutely exist. Designers must recognize the influence between common experiences and different experiences, so as to be able to design creative products with both universality and individuality.

2.4.2 Topological Visual Perception

“Where does the visual process begin?” (Pomerantz, 2017). In our daily life, we see a bird on the tree, its background is a small forest; in the picture, we see a plate of fruit, its background is its table, and so on. How on earth does vision begin to separate graphics from the background and see objects? When we look at something, such as a bird or a plate of fruit, we must first separate it from its background. According to the perception theory of topological properties, it is the early identification of topological invariant properties that separate the figure from the background (Hoffman, W. C., 1985).

Topology describes the properties of graphs that remain unchanged during rubber film-like deformation, such as "connectivity" and "number of holes". The properties of "connectivity" and "number of holes" remain unchanged when the object is smoothly deformed (not broken or fused). For example, a triangle can become a square or a circle, but its connectivity (as a connected whole) remains unchanged. Connectivity is a topological property. In addition, whether there are holes or several holes in a connected circle is also a typical topological property. The doughnut ring and the coffee cup are equivalent in topological properties because they both have a hole: hollow rectangle and cross are not equivalent in topological properties, because one has a hole and one has no hole.

Under topological transformations, topological properties such as connectivity, the number of holes, and the inside/outside relationship remain invariant (Chen, 2005). In contrast, symmetry, orientation, size, parallelism, and collinearity are properties of Euclidean geometry. As mentioned above, it has been shown that people can recognize

topological differences faster than Euclidean geometric differences. In addition, it is likely for people to direct attention to topological differences during visual exploration of scenes. Visual attention follows a scan path comprising fixations and saccades over a stimulus. Saccades are rapid movements of the eyes between positions of rest (Sperling, 1995), whereas fixations are eye movements to maintain an object within the visual field. Therefore, fixations are pauses between saccades for the visual system to gather information. The process of visual attention, namely, the switching between saccades and fixations, can be explained through early topological perception. There are two basic propositions about the beginning of the visual process in the study holistic of perception: early feature analysis and early holistic registration. In early feature analysis, perception proceeds from local elements taken as features to their integration into a whole (Treisman, 1980), whereas in early holistic registration, perception proceeds from global properties of a visual scene to the analysis of local features (Navon, D, et al., 1977). Consider the case of topological differences being more discriminable than topologically equivalent objects despite their differences in local features (Chen, 1982), the three experiments are shown in Figure 5, 6, 7. Early topological perception precedes the perception of local features, and global topological variations can receive more attention than local geometric differences. In Figure 5, the experiment compared visual perception to a line segment with that to a line segment that was a part of a connected figure. In the procedure, four subjects reported which side the line was on for each presentation. The duration of appearance was 50 msec. The target line as a part of a connected whole was reported correctly on 86 percent. When it was alone, the correct report was 55 percent. This result indicates that the connection structure can facilitate the detection of the target line as a part of it.

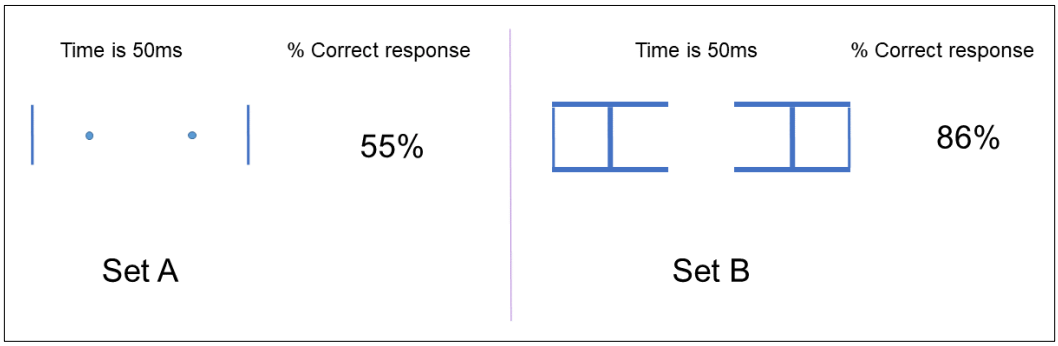


Figure 5 Visual topological perception (a)

In Figure 6, four subjects reported which group figures were different in a 5-msec presentation. The visual perception was sensitive to a hole (a ring) and one with no hole. The stimulus containing a ring was significantly better than one containing a square or a triangle [t(5)=8.78 and t(5)=6.12, respectively, p＜.01].

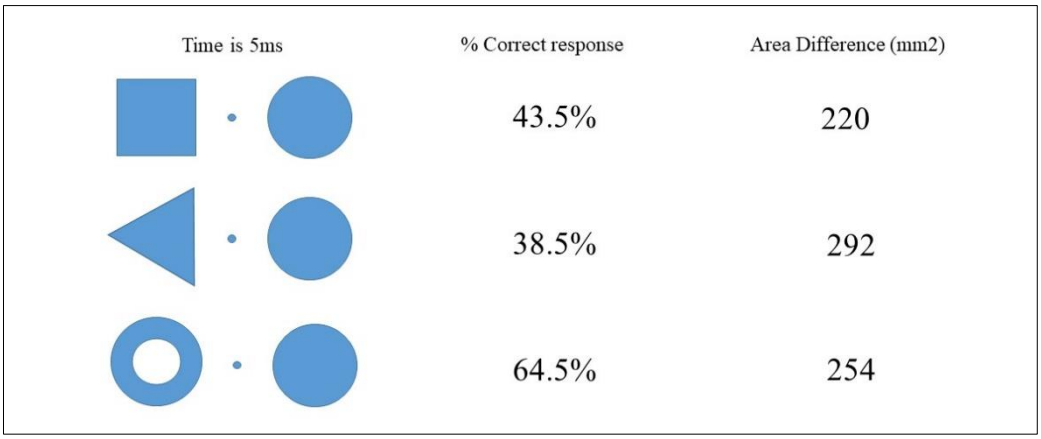


Figure 6 Visual topological perception (b)

In Figure 7, the two target lines are different both in position and slope in set A. The same target lines and an additional circle in each stimulus, so that one line was in the circle and another one outside. The eight subjects were required to indicate which line was the first appearance. The mean of set A was 59.2 percent and with set B, 79.1 percent [t(7)=7.17, p＜.001].

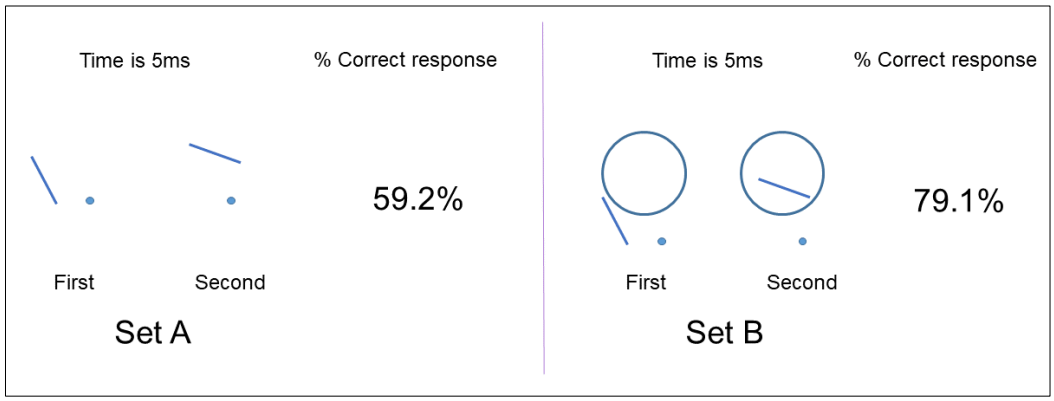


Figure 7 Visual topological perception (c)

2.5 Attention and product innovation

Attention refers to the ability of a person's psychological activities to direct and focus on something. Attention is an old and eternal topic. Attention refers to the direction and concentration of people's psychological activities towards certain external things (Schneider, W et al., 1977). It is the ability of five information channels, namely, vision, hearing, touch, smell, and taste, to pay attention to objective things. Attention is classified according to the channel of use: visual attention, auditory attention, and tactile supplemented attention. Attention is the direction and concentration of psychological activities to certain objects, and it is a common psychological characteristic accompanied by psychological processes such as perception, memory, thinking, and imagination (Buschman, T. J et al., 2015). Attention has two basic characteristics: one is directivity, which means that psychological activities selectively reflect some phenomena and leave the rest of the object (Posner, M. I et al., 1980). Secondly, centralization refers to the intensity or tension of psychological activities which remain on the selected objects (Treisman, A. M et al., 1980). Directivity is the choice of many stimuli that appear at the same time, and concentration is the suppression of interference stimuli. Its generation, scope, and duration depend on the characteristics of external stimulus and human subjective factors (Posner, M. I et al., 1990). Attention usually refers to selective attention, that is, attention tends to selectively process certain stimuli

and ignore other stimuli (Eimer, M., 2014). It is the human sensation as vision, hearing, taste and the perception about consciousness, thinking at the same time to select and focus on a certain object excluding other factors. When people pay attention to something, they are always perceiving, remembering, thinking, imagining, or experiencing something. People can not perceive many objects at the same time, only a few objects in the environment. To get a clear, profound, and complete reflection of things, we need to make psychological activities selectively point to the relevant objects. When people are awake, they always pay attention to something at every moment. Usually the so-called "not paying attention" is just not paying attention to what should be pointed to at present, but paying attention to other irrelevant things (Greenwald, A. G et al., 1984).

Regions of interest extraction is an area of interest when people observe and understand images. The method of expressing image with interest can reflect the importance of image area, highlight the main content of the hometown, and eliminate the interference of visual information such as the background (Clement, J et al., 2013). Visual attention is a biological mechanism that enables the biological vision system to quickly screen and process some important information in the visual scene. Visual attention is a biological mechanism that enables the biological vision system to quickly screen and process some important information in the visual scene (Peelen, M. V et al., 2014). When visual information enters the cerebral visual cortex through the retina-lateral knee body, the processing process is divided into two parallel pathways: one is the ventral pathway, which is mainly responsible for processing and expressing object characteristics; the other is the dorsal pathway, which is mainly responsible for processing movement and other spatial information (Mishkin, M et al., 1983). The two pathways interact with each other to help people quickly recognize things quickly and effectively. The method based on visual attention mechanism simulates the process of human visual perception (Janiszewski, C et al., 2012). The salient region of the image is regarded as the region of interest, which makes the extraction result more in line with

people's physiological characteristics.

Visual attention is vital and often the only way to acquire information about products shapes in consumer choice context (Behe, B. K et al., 2015).

Chapter 3

Case study impact of topological perception on attention to product shape

Content

Chapter 3. Case study impact of topological perception on attention to product shape

3.1 Topological perception in the shape of product

The shape of a product can be simplified to its basic geometry from a global viewpoint. In product iteration process, the shape properties would be altered for competing, while others remain invariant, especially identity for brand properties. There is a way to clarify the relationship between the properties and their levels of structural stability. According to German mathematician Klein's Erlangen program, any geometry is dealing with invariant properties under a certain transitive group action (Kisil, 2010). Using this principle, he built a hierarchy of geometries, stratified in ascending order of stability: Euclidean geometry, affine geometry, projective geometry, and topology, which provides the highest stability (Kisil, 2012). Various studies on perceptual organization have demonstrated that the psychological reality (i.e., psychological representation of knowledge) of Klein's development reveals a functional hierarchy of shape perception. Perceptual organization is the grouping of parts or regions of the field with one another, and the differentiation of figure from the ground (Rock, 1986). This functional hierarchy is remarkably consistent with the stratification of geometries. For instance, the reaction times for perceiving differences in geometry are closely related to the geometrical stratification related to form stability (Chen, 2005). Specifically, the highest stability of topology provides the shortest reaction times among the gradations of geometry. In other words, people perceive topological features before any other geometrical variant. Therefore, we addressed customers' attention to topological differences in the shape of products to foster innovative processes. Under normal circumstances, customers integrate information from stimuli with previous knowledge (Kruglanski et al, 2018). Especially for

consumer products, consumers may be familiar with their shapes by recalling related memories. When a product with a novel shape is presented to consumers as a marketing stimulus, they integrate information from that stimulus with the previously known shape, and greater differences are likely to elicit more of the consumers' attention.

3.2 Repertory grid technique (RGT)

There are two difficulties in understanding tacit knowledge, intuition, insight, and automation in the experiments performed in this study. The first is that we need to extract the cognitive results generated by the shape of the product. After all, product appearance consists of many elements, of which shape is only one part and is related to the other elements. We can consider two-dimensional graphics to study product shape. The second difficulty is applying topological perception to investigate product shape. Great improvement can be found in the transition from geometrical patterns to product shapes. It may be challenging to determine the effect of topological properties on the visual perception of product shape because topology is unfamiliar to the general public. Therefore, we employed a method to infer thoughts or ideas that are not consciously held by individuals. Specifically, to make tacit knowledge explicit, we adopted the RGT.

The RGT is derived from the personal construct theory proposed by cognitive psychologist George Kelly around 1955. This psychological theory aimed to explain the varying viewpoints and attitudes of people towards events in the world (Kelly, 1955). Hence, it has been used to explore the cognitive psychological structures hidden in the subconscious of individuals. For instance, over the last four decades, it has been widely used in cognitive science, education, marketing management, development programs, etc. RGT can be applied to a variety of fields because it provides unique and useful data collection and analysis methods to quantify people's attitudes, feelings, and perceptions (Easterby-Smith, Thorpe et al, 1996).

Kelly claimed that people develop their personal constructs for construing things when they feel them in the phenomenal world. A construct is not the same as a concept;

it is defined as a similarity and a difference at the same time. (Björklund, 2008). Consequently, when predicting the world and governing their behavior, people rely on their constructs, which are bipolar and are arranged within a hierarchical personal construct system. Therefore, individuals compare experiences with the predicted results provided by their constructs when perceiving something. If the experience and construct agree, the original construct is strengthened, whereas predictions not consistent with reality lead the original construct to be questioned and revised (Hill et al, 2016). For instance, a construct related to being kind must have a contrasting pole, in this case, irritability, to establish a bipolarity for comparison and reference. We feel that a person is very kind from his appearance. After a period of contact, we find that the person is indeed friendly or has an irritable personality. Our existing construct for this person is being strengthened or revised.

The RGT is roughly divided into three stages. First, the research problem and its appropriate elements should be established. Elements in the RGT correspond to cases of the research problem. For example, a study on a ball game can have as elements of different kinds, such as basketball, rugby, tennis, or badminton. Second, constructs with their two opposite poles should be elicited from the elements. We present raptors continually as an example for explaining how to elicit constructs from elements. Three elements are selected for one time, and the subject is asked the eliciting question:

-Can you choose two similar elements among the triad of elements which are different from the other one in some way?

-Basketball and tennis

The next question was

-What is the reason for separating that pair from the other one? Use just one or two words for each pole.

The left pole is the ball. The right pole is non-spherical.

The steps for eliciting another construct and linking to elements can be repeated several times until construct generation or subject is exhausted. The eliciting of

constructs is listed in Table 1. Finally, a grid is established by linking constructs to elements. All the elements are rated using bipolar constructs by using Likert scales of 5, 7, 9, or more. The result is recorded as an array in a row in a repertory grid.

Table 1 The eliciting of constructs

Alike elements	Different element	Construct
Basketball, Tennis	Badminton	Ball - non-spherical
Tennis, Badminton	Basketball	Small - Big
Basketball, Rugby	Tennis	expensive - cheap

The research process that we adopted in this study can be summarized as follows:

We selected bicycles as research objects and considered their topological properties.

We selected the latest models from existing bicycle brands. Specifically, we selected those models that have won leading product design awards or bicycle design awards, and a prototype of concept bicycle designs. We compared the selected bicycles with a prototypical bicycle. The cases showing the most significant differences were considered as research objects for further comparison.

We used the selected bicycle models as elements for the repertory grid technique (RGT). Then, we extracted constructs from these elements with the help of experts, and other participants rated the elements in terms of the defined constructs. Finally, we analyzed the results.

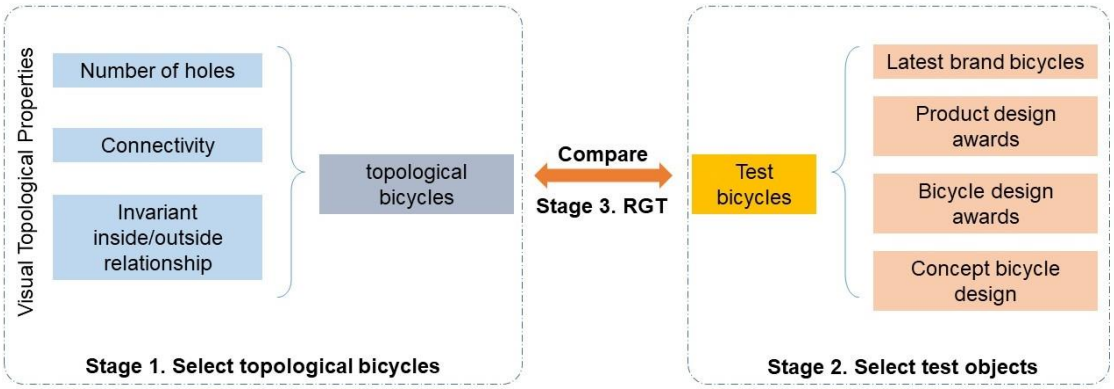


Figure 8 The framework of topological perception in the shape of products study

3.3 Experiment design

3.3.1 Experiment objects

We selected bicycles as objects in this study for three reasons. First, the attributes of the product shape, which in bicycles are approximately two dimensional, i.e., planar, are suitable for structured analysis. Most users assess bicycles from the side-view showing the wheels and frame, whereas other views are rarely considered. Moreover, two-dimensional product shapes are more consistent with topological perception because visual topological properties are based on two-dimensional manifolds. We investigated several bicycle designs and determined that many innovations conform to the following topological transformations that we identified. In addition, we conducted a thought experiment on the perception of spokeless bicycle wheels. We found that most bicycle wheels contain spokes radiating from the center of the hub, and the array of spokes is perceived as a disc compared with a spokeless wheel, which can be seen as a ring (Dodwell, 1983). These two shapes, disc, and ring are topologically different. In general, the hub is located on the inner side of the rim and centered. The hubs of some recent transmission bicycles are still inside the rims, but at the edge, whereas others are outside the rims and visually connected to the tire. Such changes are reflected in the visual topology property of outside/inside. The seat, handlebar, chainrings, and wheels are connected through the frame. Hence, the frame can be evaluated in terms of connectivity, and changes to it determine connectivity transformations. Overall, we identified three visual topological properties of bicycles, namely, disc/ring wheels, the location of the hub, and connectivity. Second, we chose bicycles by their popularity, as they are used from children to the elderly alike, in both developing and developed countries. Therefore, bicycles are very suitable for applying the RGT, as almost anyone can evaluate their elements according to constructs. Third, the continued development of the bicycle industry fosters designs and widespread use to promote the low-carbon

lifestyle currently pursued worldwide. Therefore, the results of this study can be useful for the design and development of bicycles.

The prototypical bicycle in this study is based on the concept and pictures of bicycles available in the Encyclopaedia Britannica (Berto, 2017), from which we selected a typical bicycle as reference. According to the encyclopedia, a prototypical bicycle is a 'two-wheeled steerable machine that is pedaled by the rider's feet,' where

the wheels are mounted in-line in a metal frame, with the front wheel held in a rotatable fork. The rider sits on a saddle and steers by leaning and turning handlebars that are attached to the fork. The feet turn pedals attached to cranks and a chain wheel. Power is transmitted by a loop of chain connecting the chain wheel to a sprocket on the rear wheel.

The prototypical bicycle for this study is shown in Figure 9.

Figure 9 The prototypical bicycle for this study

3.3.2 RGT elements

We chose 30 types of bicycles from the latest models of existing bicycle brands (e.g., Storck, Pinarello, and Nicolai) for evaluation. We considered models that have won leading product design awards or bicycle design awards (e.g., Core77 Design Awards and International Bicycle Design Competition awards), and some bicycle models at the stage of design concepts (e.g., Yanko Design and Bicycle Design). Among the models, we selected the four bicycle models most consistent with the three abovementioned

topological transformations as key examples (Figure 10). To avoid the influence of color, all pictures were grayscale on a white background. In addition, the prototypical bicycle was placed at the lower-right corner of each picture, as illustrated in Figure 11. Thirty participants assessed the differences between the test and prototypical bicycles in each picture. The participants were college students with an average age of 20 with an equal gender ratio. Scores were given on a 7-point Likert scale, where the lowest and highest differences were ranked 1 and 7, respectively. Using k-means clustering from the average of each bicycle, nine bicycles exhibited the highest differences, and we selected them as elements for the RGT. The nine types of bicycles are shown in Figure 12 and include the four key types regarding topological characteristics.

Figure 10 The four key test bicycles

Figure 11 Two sample pictures of comparison between the test bicycle and the prototypical bicycle

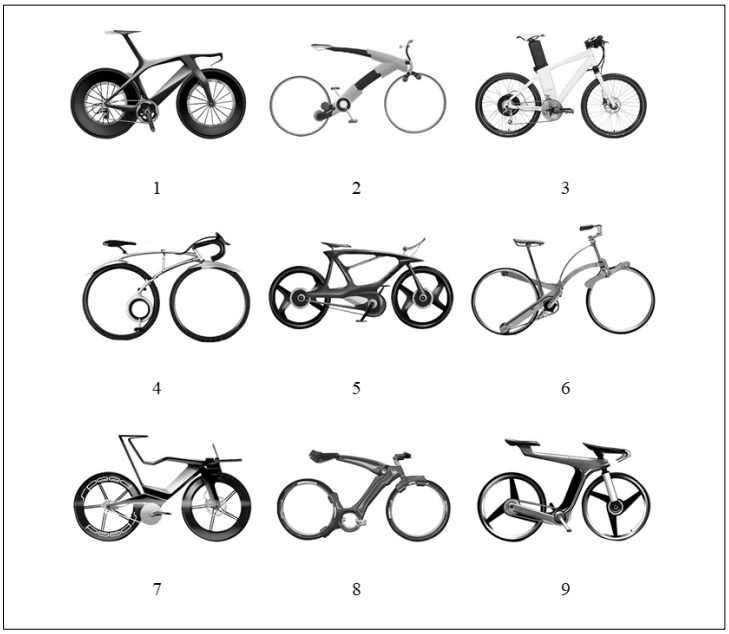


Figure 12 The nine bicycles with the largest degrees of difference, and their codes

3.3.3 Constructs from elements

We used the RGT to determine how people distinguish the differences between the nine test bicycle models and the prototypical model. Each of the nine models was presented on an A4 size page, clearly showing details from every part of the bicycle. We invited seven experts with high knowledge of bicycles to decide on the constructs. The experts included product designers, mechanical teachers, product design professional teachers, product design graduate students, and bicycle enthusiasts. For the convenience of the experts, we numbered cards showing the bicycles as in Table 2. Without knowing the bicycle (i.e., cards facing down), each expert-selected three cards randomly and divided the three pictures into two groups. These groups were intended for the expert to discriminate bicycles in opposite poles by pairing similarities and leaving out the dissimilar bicycle model. We then structured the bipolar attributes of similarity and dissimilarity. Each subject created the constructs within 60 to 80 minutes. All the generated constructs are detailed in the Supplementary Material. Words related to the seat and chainrings were mentioned 6 and 13 times, respectively, whereas 6 references were made to the chainrings or transmission, and the wheels were mentioned

8 times. The bicycle as a whole was mentioned 8 times. Therefore, we established five categories regarding constructs from the whole bicycle, its seat, frame, wheels, and chainrings and defined seven constructs (Easterby-Smith, 1980) as detailed in Table 3. None of the constructs use the terminology of visual topological properties, such as holes, connectivity, and inside/outside. Instead, we used elicitation words. The use of such words was aimed to simplify the participants' evaluations and prevent confusion when assigning scores, as may occur if using the topological properties for scoring. The experts also mentioned general characteristics such as 'beautiful' and 'avant-garde', and some of the bicycles were mainly seen as 'curvilinear', 'dynamic', or 'strong'. Such descriptions can be considered more subjective and related to aesthetics, and therefore not suitable for evaluation. In addition, if we had used pairs such as conventional–spokeless wheel as a construct, it would obviously refer to one of the key test bicycles, and no useful findings could have been obtained. Still, the defined constructs are suitable for evaluating aesthetics and provide intuitive concepts on the bicycles. Note that we used the key test bicycle models to establish differences after applying the RGT.

Table 2 Seven constructs from elements

Positive	**Negative**
Extraordinary	Common
High-Tech	Low-Tech
Novel Wheels	Common Wheels
Novel Frame	Common Frame
Novel Seat	Common Seat
Curiosity about Transmission	No Curiosity about Transmission
Desire to Ride	No Desire to Ride

Clear relationships between the defined constructs and topological properties can be determined. Specifically, the construct extraordinary–common refers to the general hypothesis of this study, i.e., that topological properties are distinguishable in product shapes. When a topological variant appears, people should be able to notice it. Topological variations occur in product shapes with novel structures and functions,

which are ideally inferred by the viewer, thus facilitating the evaluation of the effect of topological properties. For instance, high- and low-technology bicycles are defined regarding the whole body by a perceived sense of science and technology embedded in the design. More specifically, characteristics such as the lack of hubs and spokes, a circular chainring evenly placed in the rear wheel, and suspended seats give people a sense of high-technology. To further explore the effects of topological properties on people, the other defined constructs are related to the topology of relevant parts of the bicycle. The construct novel–common wheels refer to holes and the inside/outside relationship. In addition, novel–common frame and seat refer to connectivity. In fact, the frame connects all parts of the bicycle together, and that of a prototypical bicycle is similar to a diamond composed of two triangles, establishing the most common shape with the connections seat–handlebar, wheels–chainring, and seat–chainring. Novel frame shapes can subvert the conventional one and create new connectivity patterns between the various parts. The transmission construct refers to holes and the inside/outside relationship, and the degree of curiosity about the transmission reflects attention towards these properties. Whether a subject desires to ride the bicycle allows us to learn about the level of interest towards bicycles with different topological properties. We considered that when people see a product with a high degree of novelty, they are naturally willing to use it. Such an intention is visceral influences. People take extreme actions because of visceral influences. Many of decisions are made under the influence of intense visceral states (Loewenstein, G., 2000). The desire to ride a bicycle is fostered if a novel transmission is present and increases the probability of discarding the other five bicycle models with a chain driving rear hub transmissions.

3.3.4 Rating of elements

The thirty participants rated all the elements according to the two poles of the defined constructs on a 7-point Likert scale. We obtained thirty formats and eliminated

two invalid ones because the scores are all similar in the formats. Next, we did the Shapiro–Wilk test on the remaining 28 formats. The Likert scale should be a sequential scale. For sequential scales, only the median can be calculated, and not the mean value. Nevertheless, many RGT analyses have been conducted to calculate mean values. The format of scoring is listed in Table 3. The rows indicate the constructs, the column indicates the test bicycle, and the number indicates the number of the test bicycle. We used the free WebGrid Plus software (http://webgrid.uvic.ca) for RGT. The resulting grid is displayed in Figures 13 to 15.

Table 3 Scoring format

Elements / Constructs	1	2	3	4	5	6	7	8	9	
Common										Extraordinary
Low-Tech										High-Tech
Common Wheels										Novel Wheels
Common Frame										Novel Frame
Common Seat										Novel Seat
No Curiosity about Transmission										Curiosity about Transmission
No Desire to Ride										Desire to Ride

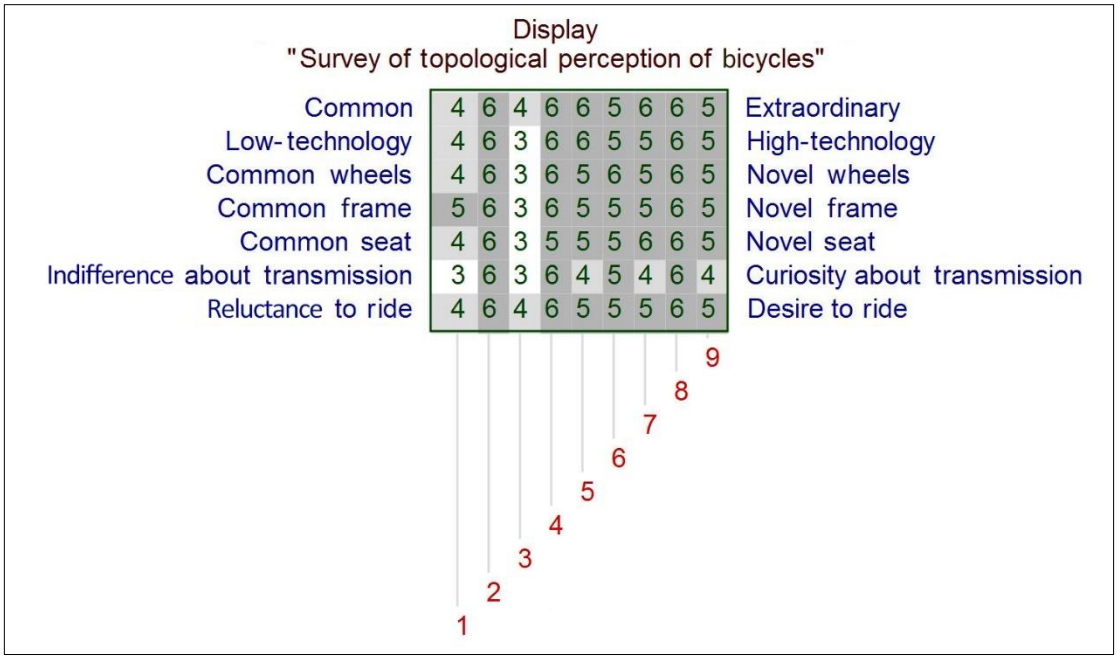


Figure 13 Display of Constructs in Grid

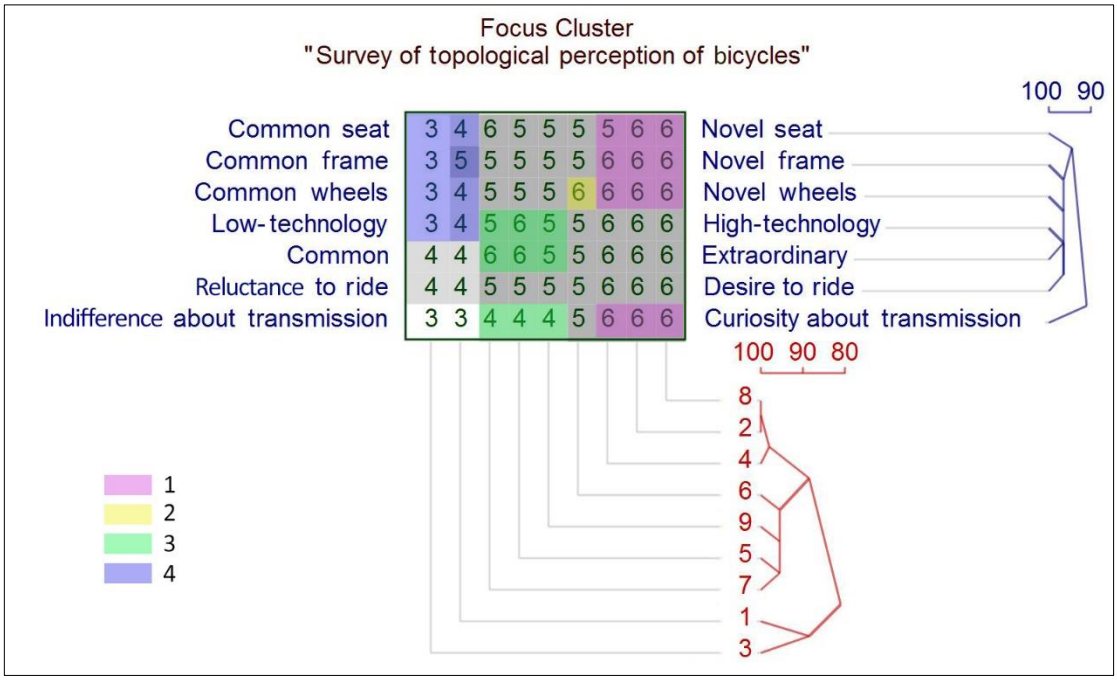


Figure 14 Focus Cluster Display

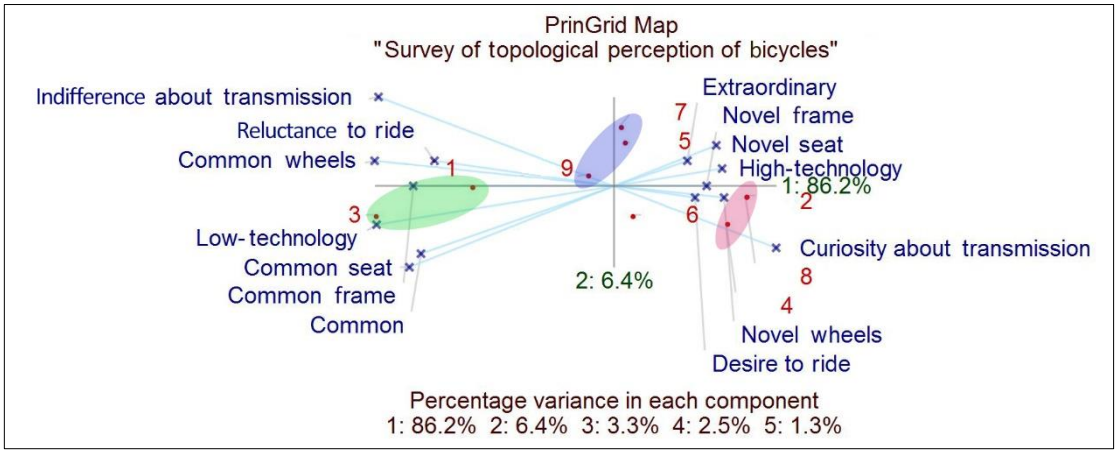


Figure 15 Principal Component Analysis

3.3.5 Result

The result of the focus cluster is shown in Figure 14. The rows show the elicited constructs and the element columns in the grid. Based on the scores of the respondents, the similarities of elements and constructs were respectively clustered by focus analysis. Focus analysis can be used to understand the clustering relationship between elements and constructions. It can be used for cluster analysis of the relativity between elements and constructs. On the other hand, it can also be used as an identification tool for cognitive relativity, namely, a comparison of the performance of the tested bicycles in various constructions. The Principal Components Analysis identifies different patterns of numbers in the grid based on the program, and these programs calculate the degree to which the ratings in each row are similar to each other. Iteratively, it attributes each of the different modes, the total variance of the components, to it as much as possible. This study set two threshold values for clustering. From element clustering, the threshold value, 95, we found a strong resemblance between bicycles 8, 4, and 2. 9, 5, and 7 are similar. The performance of bicycle 6 was poor in the four key test bicycles and was more similar to 9, 5, and 7. The performance of bicycles 1 and 3 was similar, but they have the lowest similarity with other elements. From the perspective of the cluster analysis of the constructs, the threshold value, 96, High-Tech, Novel Wheels,

and Novel Frame are even more similar. Transmission as a construct is the most significant difference for other constructs. The results of RGT for the cognition of the nine bicycles are explained below.

Four cognition results can be concluded (i.e., different color grids) from the cluster analysis of the scores of the participants. The first result is that bicycles 8, 2, and 4 have the highest scores with respect to constructs wheels, frame, seat, and transmission. Taking the wheel as an example, the wheels of the three bicycles are similar to circles, such as holes, without any other decoration. The wheels of bicycles 5, 7, and 9 are novel styles from the aesthetic point of view. The scores of bicycles 8, 2, and 4 are higher than those of bicycles 5, 7, and 9. The results of the frame, seat, and transmission are also similar. This shows that cognition based on topological variant has significant advantages over aesthetic variant. Although the score of bicycle 4 is lower than that of 7 with respect to the construct seat, the seat and frame are a whole in 7, namely, the relation of two parts change from outside to inside. The reason for this is still the topological variant. Furthermore, the priority recognition of topological advantage is reflected in the internal comparison of bicycles 8, 2, and 4. They are similar except for the construct novel common seat. The seats of bicycles 8 and 2 are only connected to the head tube and suspended, whereas that of bicycle 4 is connected to both the rear wheel and head tube, thus appearing to be more stable and common. The suspension state is more subversive to the experience of the stability of the seat. Bicycles 8, 2, and 4 were geared and are highly disruptive compared to conventional chain drives.

The second result is that the transmission of bicycle 6 is chain drive, and its topological variant was found to be the weakest among the four key test bicycles. Only the front wheel has the property of a hole and the rear wheel of the bicycle has no spokes, while other parts do not have topological variations. The seat retains a direct connection with the rear wheel, head tube, and chainrings, which is very similar to the seat structure of the prototype bicycle.

The third result is that the scores of the constructs tech and extraordinary are high

in bicycles 5, 7, and 9, and especially high in bicycle 5. However, the scores of transmission are low compared with those of tech and extraordinary. We found that the three bicycles have a high-tech image and excellence, and this evaluation is based on emotion, from the aesthetic appreciation of the first reaction to the shape. There were little influence and curiosity in the minds of participants.

Bicycles 1 and 3 have low scores for every construct. The two bicycles have no characteristics of the topological variation. The structures are similar to the prototype. There was only partial decoration and improvement in form. 1 possesses advantages over 3 in the constructs seat, frame, wheels, and tech. Aesthetic appreciation is the cause of this difference.

We also verified that bicycles 1, 3, 5, 7, and 9 (i.e., the bicycle models not considered as key types) were considered as beautiful and avant-garde, which confirms their selection as the top nine bicycles with the most significant differences. During the interviews with experts, we learned that these bicycles attract attention mostly by styling aesthetics. In terms of their scores and cluster analysis, there was a clear distinction between this group and the four key test bicycle models. Hence, these two groups of bicycles (i.e., key types and the others) were considered to be the most attractive, but they result attractive for different reasons, namely, topological properties and aesthetics. The topological variant in bicycle shape can indeed attract people's attention to the engineered structure, which is prior to attention caused by aesthetics.

3.4 Discussion

3.4.1 Findings and analysis

The results of this study suggest that the perception of topological properties is applicable to variations of product shapes and plays an important role in the human recognition of bicycles. Furthermore, people tend to pay early attention to bicycles with

obvious topological variations, as demonstrated by the four key test bicycle models, which received the highest scores in the seven constructs.

Two perspectives can be addressed regarding these findings. First, topological properties play a role in visual perception of bicycle shape, and second, bicycles receive more attention from customers when topological variations are applied to the shape. Considering the first perspective, the wheels variations contained and lacked spokes and hubs, and their shapes appeared as empty and filled, i.e., like rings and discs, respectively. In addition, the connection between the seat, chainring, and wheels varied with the frame. Topologically, bicycles were presented as holes with varying connectivity and inside/outside relationships. Hence, the theory of topological perception is applicable to the recognition of product shape. Novel transmissions, structures, and user experiences can be inferred when a bicycle contains unseen topological variations. Considering the second perspective, new experiences can be first inferred visually and attract the customer's attention. Overall, combining the two perspectives, our innovative process of applying the visual perception to analyze topological variations of shapes and eliciting new user experiences from topologically novel shapes was demonstrated on bicycles.

3.4.2 Contribution to product design

This study can provide insights into the design of product shapes. There is a debate about whether product-related beliefs derive from holistic visual perception or from atomistic perception. One way to conciliate these perspectives is to assume the occurrence of both holistic and atomistic processing (Bloch, 2011). We consider that people first perceive a product as a whole, and then individual elements may become salient if the form elicits further processing. Especially with familiar products, people demonstrate conventional recognition for the detailed functionality and the position of each part in the holistic form. In fact, people are familiar with the relative position

among parts and their function. For example, the Dyson bladeless fan and a prototypical blade fan compose a pair for topological perception. Specifically, the blade fan changes from an approximate disc into a ring, i.e., a hole appears in shape. Also, the relative position between the fan blade and guard changes, as the blade has been moved from the inside to the outside of the guard (i.e., a topological variant has occurred), and hence consumers are easily attracted to the unique appearance of the bladeless fan. Consumers may use the product appearance for categorization, where shapes in a category may be considered as typical prototypes. When a prototype features a topological variant, it is likely that new technology and new materials have been employed. Hence, such products are very likely to be noticed by consumers by the implemented topological variations. This is because the perception of global topological properties may be a primitive and general function of the human visual system. The essence of topological variant is that the structure of existing products changes and the cognitive logic of people changes subversively. Aesthetic-based design quantitatively increases the brand image of a product in people's memory, which stimulates emotional fluctuation. The results of the experiment in this study show that subversive changes in cognitive logic arose prior to attention compared to emotional fluctuations. The topological variation is advantageous for comparing aesthetic decorations in product design.

3.4.3 Limitations

In this study, we conducted a visual perception experiment on topological properties in bicycles, and hence it has some limitations. For instance, as the bicycle shape can be assessed in a plane, it clearly shows topological properties. In three-dimensional product shapes, topological features may be less obvious. For example, chairs should be assessed from more perspectives than bicycles, and their topological properties can be more obvious from one view than from others. Therefore, it is necessary to consider topological properties according to both the viewer’s perspective and shape, and then

create products that can receive attention from consumers by the topological properties.

3.5 Summary

In this chapter, we have illustrated the advantage of adopting varying topological properties for products to receive more consumers' attention, although this does not imply that the resulting product will be a successful design. In future research, we will extend topological perception to more product categories and combine this type of perception with other product innovation methods. In addition, future research will also measure the quality level of creative thinking generated by topological variations. Some scholars have proposed that products that differ slightly from the prototypical instance are more positively evaluated than those that are either very typical or atypical (Rucker et al, 2012). However, regarding aesthetics, form structure, and topological perception may be integrated, and connectivity, continuity, and compact visual expression can exude formal beauty. For instance, product design often uses keywords but turning them into visual images is a complex process (Nagai et al, 2011). Thus, transforming keywords into visual images and combining visual topological properties may enable products to meet design requirements and gain visual attention from potential customers. This involves the combination of vocabulary and organizational rules in product form design. The form vocabulary represents the keywords and can be combined into topological properties. The use of topological properties in representing aesthetic impression, semantic interpretation, and symbolic association should also be examined towards making topology more natural and harmonious in product form and design.

Chapter 4

Case study of Topological Variations-Oriented Approach for Creativity Generation

Content

Chapter 4. Case study of Topological Variations-Oriented Approach for Creativity Generation

This chapter introduces a thinking model aimed at promoting the effect of product innovation by using topological invariant and variant. The research is to study product innovation from the perspective of the logical relationships among the four territories: human, product, activity, and experience. These logical relationships can be expressed as a series of activities or behaviors in the process of people use products, and then people generate experience at the psychological level. Product innovation can be recognized according to whether there are any unprecedented relationships in the four territories. Topology is a branch of mathematics that aims at studying invariant properties and relationship under continuous transformation. Conversely, when the topological variant occurs, a new relationship emerges. In the experiment， we take the four territories and corresponding relationships similar to rich pictures performance，as a visualized plane, and make topological variations on this plane to inspire persons to come up with some new relationships. The visualized plane named innovative thinking model in the study, and we can get the relative original concepts and these concepts have a positive effect on product innovation.

4.1 Rich Pictures (RPs)

Soft systems methodology (SSM) is an approach for attacking problematical, messy situations of all kinds (Checkland, P., 2013). The process is action-oriented and inquires into problematic situations. Users take action to improve the situations by learning their way (Campbell Williams, M., 2000). The learning shows an organized process that the situation is explored to inform and structure discussion about a situation and how it might be improved, using a set of models of purposeful action as intellectual devices

and tools (Bell, S et al., 2013a).

RPs originated in SSM (Lewis, P. J., 1992). It involves a drawing of the holistic situation of the target subject. The pictures present the key elements of a situation and do not have a specific format or language. There is no fixed way of drawing RPs (Berg, T. 2015). There are as many styles as analysts, and the same analyst will find different styles useful in different situations.

Four Principles of RPs:

Firstly, the principle of image. Compared with abstract characters, the human brain is more sensitive to images, and vivid and interesting images will leave a deep impression on the brain. The RPs uses images to stimulate the brain effectively (Bell, S et al., 2013b). The neuropsychologist confirmed the asymmetric "division of left and right brains" theory through the split-brain experiment (Galaburda, A. M et al., 1978). The experimental results show that the left hemisphere is mainly responsible for language, understanding, logic, analysis, judgment, classification and so on, while the right hemisphere is mainly responsible for images, imagination, space, emotion, and intuition, music, art, inspiration and so on. Perceptively speaking, the left brain is the "logical brain", responsible for logical analysis; the right brain is the "illogical brain" or "image brain", responsible for images and imagination. The right brain is the process of seeing or imagining images in the brain.

Second, the divergence principle. The central map of RPs can lead to many first-level branches, and the first-level branches can lead to many second-level branches. Taking one point as the center and spreading out around can effectively exercise divergent thinking and further improve creativity and inspiration (Monk, A et al., 1998). RPs is just unfolded by the center map, and gradually spread to the first-level branches, and each first-level branch is a center, and gradually spread to the second-level branches, and so on. Through this formal structure, RPs can organize all knowledge points or information points together, making this knowledge or information more organized, structured and systematic in the brain.

Third, the convergence principle. Convergence occurs when divergence occurs. They are relative. Divergent thinking is very important, but convergent thinking is also very important. Divergent thinking is the embodiment of associative ability. It is really very important. It can make you feel free. There are many associations. There may be many good ideas, but it may also associate a lot of useless information. At this time, we need convergence thinking, and remind ourselves of the starting point and the key information from time to time. RPs is organized according to the structure of the center and branch. It can diverge according to the center and branch. So divergence is constrained (Avison, D. E et al., 1992). So, RPs can be used freely when thinking.

Fourth, the active principle. In 1946, American scholar Edgar Dale put forward the theory of the learning pyramid. The learning pyramid shows in the digital form how many content learners can remember in two weeks with different learning styles (Jackson, J. 2016). A big difference between the RPs and traditional notes is that RPs need to be analyzed, thought and summarized actively. Drawing RPs is equivalent to re-combing the knowledge content of learning, clearing up one's own ideas, and better understanding and absorption of this knowledge in thinking and summarizing, and then expressing the knowledge after understanding and absorption, in the form of “image + branch + keyword” RPs (Sylvester, A et al., 2007). RPs is a process that allows you to think actively, absorb knowledge.

Four Elements of RPs:

Image. Compared with abstract character numbers, our brains are more sensitive to images and more impressive. Because the image stimulates the right brain. Logic analysis ability and abstract thinking are really very important. We need to gradually exercise our powerful logic analysis ability. At the same time, compared with words, the human brain prefers images and scenes. Images make memory easier and more solid, and even unconsciously and effortlessly learn knowledge in the corresponding scenes (Farhadi, A et al., 2010). RPs, as a tool for sorting out knowledge and planning, can make memory stronger and clearer. One of the main reasons is the use of images. If you

want to stimulate your brain better, you can use your RPs to enrich more images on it.

Colour. The color combines the shape features of the object to facilitate association (Earl, L et al., 2005). So when drawing RPs, you can draw some auxiliary sketches and fill them with beautiful colors, which not only makes yourself like them but also makes them more beautiful and vivid.

Line. The lines of the RPs include trunk and branch, and the trunk is a first-level branch. The lines of the main branch are generally thicker and longer, while the lines of the second branch and the third branch are generally shorter and thinner. The lines in the RPs are all curves, and they are smooth curves at the end. The reason for using curves is that they are very flexible. When you want to add new content, you can introduce a curve. Moreover, the organizational form of the RPs makes it easy to add content with curves because there are many blank areas in paper or plane (Valente, A et al., 2010). The important reason why the end is a smooth curve is that there are keywords on the line. Therefore, the lines in RPs should be curved and smooth at the end.

Keywords. Keywords are usually written on the lines of the trunk and branches. As the name implies, keywords are words that extract key information about what we learn (Prior, L. A et al., 2012).

Products innovation is a complex systematic project, and the lifeblood of firms competing in dynamic environments (Slater, S. F., 2014). Various theories have attempted to disentangle the drivers of innovation, e.g., involving the cultural background, technology innovation, marketing strategy, and consumer psychology. RPs can be applied in product innovation when a firm faces a complicated and confusing situation (Mazijoglou, M et al., 1998).

4.2 Relationship between the four territories

Products can be seen instruments that help people accomplish some matters they cannot

achieve with their bare hands. People and products perform a series of activities in the process of their interaction, and people generate some experience. With the development of the design concept, the customers and designers focus on the experience of users, even to improve existing products for some kind of experience. Therefore, the relationship between products and human was constructed through four domains: product, human, activity, and experience. The four territories constitute a system, they are in a logical order, i.e., people created corresponding products to achieve certain goals and needs in some environment, and then people and products respectively prompted to make a series of activities, and the emotional experiences generating out of the people. The following is a detailed description of each logical relationship.

4.2.1 Environment

In the process of product design, the environment is an important external condition that affects product appearance design. The appearance of the product needs to be adapted to its use environment to make people feel harmonious and comfortable. Designers need to focus on the use of product scenarios, using appropriate color and shape, so that the product appearance and the surrounding environment are integrated, making people look very natural (Pahng, F et al., 1998). Product appearance is a part of the visual environment. Its design is not an isolated design. It is not an art design that can be carried out in isolation without environmental impact. It needs to consider many factors, such as the intrinsic relationship of products, the matching of environment and user experience (Stuart, S et al., 2007). It needs to be targeted at specific products and the correlative environment for design. For example, the installation of machine tools requires strict standard size in shape and clear appearance of products, while the large program workshop and production line group buildings in factories need not be clearly displayed. In many usage environments, a gorgeous appearance is still necessary. For

example, the appearance of Italian consumer goods can not only fully meet the needs of users, but also have a good appeal, its rich color, the use of sleek curves, more attention to the variety of patterns, many consumer goods are very successful in the design of appearance (Courage, C et al., 2005). But the product appearance design is too garish, also easy to make people tired. People need not only beautiful products but also some elegant designs. Just as in the colorful traffic flow, the elegant white car is easier to attract people's attention. Designers need to control the level of innovation. Different products depend on different environments (Green, M. G et al., 2006). In the American social context, product design is characterized by large-scale production, short product life, fashion, curve, and color design are closely related to commercial interests, which is more suitable for consumer design. In the case of special visual requirements, products can be modeled with bright colors, appropriate models and proportions. For basic engineering or commodity development, it is more important to consider environmental factors. For example, the design of new energy charging pile, first of all, the charging demand of the surrounding road environment should be taken into account, which is a well-known principle. As people become more able to live and understand life, people will pay more attention to their home environment and quality of life (Idoughi, D et al., 2012). Product appearance design needs to take this into account, not only to make its appearance and environment coordinate but also make people feel very high quality.

4.2.2 Product as the core

The emergence of a completely new product indicates a new application for people. The main object of a radical new product is to resolve the new problems and create new lives. At the beginning of the new product, technological progress is a source of many radical innovations (Govindarajan, V et al., 2004), people should cater to the product in the process of using it.

New product development (NPD) has become an important pillar for the survival and development of enterprises (Brown, T et al., 2011). Enterprises continue to develop new products and provide new products and services to the market.

NPD is an important guarantee for the survival and growth of enterprises. New technologies are constantly emerging, products are changing with each passing day, the product life cycle will be shorter. If enterprises do not develop new products and put marketable products to market, they will not be able to survive and grow for a long time. Many global companies, such as Toyota and Panasonic in Japan, Apple, HP, and Google in the United States, regard the new product development strategy as the cornerstone of enterprise growth.

NPD is an important means for enterprises to meet the needs of consumers. With the continuous improvement of people's living standards, on the one hand, people's consumption needs and habits are constantly changing, which requires more diversification and advanced. At the same time, it also provides more market opportunities for enterprises. In order to grasp and make good use of these opportunities, enterprises must constantly develop new products to adapt to them and create the market to meet the needs of consumers.

NPD is an important factor for enterprises to improve their competitiveness. In today's fiercely competitive market, enterprises should pay attention to competitors behavior and respond to competition while satisfying consumers' or users purchasing desires and needs. The experience of many successful enterprises shows that improve competitiveness and make enterprises invincible only by continuously developing new products. Competitive enterprises are committed to the development of new products to achieve market dominance.

NPD is an important condition to enhance the vitality of enterprises. Enlivening enterprises and enhancing their vitality is restricted by many factors. However, in a sense, NPD is a prerequisite to enhance the vitality of enterprises. Enterprises depend on the survival of the magic weapon is to develop new products and improve existing

products. Enterprises keep vigorous only when they attach importance to the development of new products.

Product development is conducive to promoting the improvement of enterprise production technology. Product development is a process of exploration and innovation. It is necessary to open up new technological fields and solve various complex scientific and technological problems on the basis of modern scientific and technological achievements and their application in production. Product renewal is essentially product design, structure and performance changes. It will lead to a series of corresponding changes in the original process equipment, factory building, energy, raw material, personnel quality and configuration, production and operation management model of enterprises. That is to say, product development of enterprises will inevitably lead to innovation in design, process, and equipment, so as to promote enterprises to carry out technology issuance and constantly improve the production technology system.

Finally, NPD is an important way to improve the economic benefits of enterprises. In the process of product development, new science and technology are often used, which will inevitably make new products have more technology content, higher added value, better function or performance than existing products so that they can not only better meet consumer needs, but also bring greater economic benefits to enterprises.

4.2.3 Physical ergonomics

Ergonomics is a science that studies the relationship among the three elements of human, machine, and environment in the human-machine-environment system, and provides concepts and methods for solving the problems of human efficiency and health in the system (Wilson, J. R., 2014). Physical ergonomics is concerned with human anatomical, anthropometric, physiological, and biomechanical characteristics as they relate to physical activity. It is an important content of NPD, which directly affects the user experience of products. The high-quality user experience is the sticking point to

win users and the market. In the process of product design, designers should adhere to the principle of humanization and conform to the theory of ergonomics, and best to improve the comfort and the experience.

How to make the product easy to use and comfortable is the key problem that designers need to solve. Ergonomics involves human structure, human-machine relationship, environmental psychology, and other aspects, which is an important theoretical basis for product design (Elbert, K. K et al., 2018). If the product is out of step with ergonomics, such as the height of the product, the size of the product is too large or too small, and the operation interface is too complex, which results in the product being difficult to understand, learn and operate, all of which leave bad experience for users, which is not conducive to the promotion and sale of the product. Different products have different structural characteristics, functions and usage modes, which requires designers to conduct in-depth research and analysis of products based on user needs, comprehensively use ergonomics related theories, fully consider human body structure, usage habits, environmental psychology, and many other factors, and put forward different suggestions for different products. The same solution makes the product, man-machine and environment in a relatively harmonious and unified state.

In the process of product design, designers should not only consider whether their design conforms to ergonomics, but also comprehensively consider material, crafts, color, shape, and other aspects, and do a good job in product detail design. Only in this way, the products produce practical, beautiful and comfortable to use, and they would be more easily succeed in the market.

4.2.4 Emotional experience

In a long time, the study of human emotion did not separate independently but belonged to the philosophical category. It was not until the 19th century that the emergence of German psychologist Wilhelm Wundt took place a major turning point.

Wilhelm Wundt will officially separate the study of human emotions from philosophy and try to use scientific experimental methods to study them. With the development of society, the research on Wilhelm Wundt human emotion has been divided into three branches: behavioral theory, mental theory, and cognitive theory (Carpenter, S. K., 2005).

Use and Emotion are the two most important aspects of the research on design art psychology. The former focuses on grasping the user's psychology, improving the physical quality of design, making it more in line with people's needs in perception and information processing, while the latter focuses on the user's subjective experience (Fukuda, S., 2013). Therefore, the combination of use and emotion can basically cover the whole psychological process of interaction between users and objects. Use and emotion are the two most important aspects of user psychology applied in art design. They are the concrete embodiment of the rational and perceptual needs of user psychology. They are not only independent but also interrelated and reciprocal causality. Because use involves people's subjective satisfaction and the degree of pleasure, it has the component of subjective emotional experience, or it can be said that "attractive products are better to use" (Norman, D. A., 2003). At the same time, the emotions of design art are based on purposefulness, and the mood and emotional experience of users in the process of use are also designed emotions. An important component is that "good products are more attractive" (Isen, A. M., 1993). Use and emotion are the two most important aspects affecting users psychology. There is a reciprocal relationship between them. The influence of usability may come from emotional experience, and emotional experience may also affect usability.

Emotions are a result of an individual’s judgment about the world and appraisal of interactions with the world (Desmet, 2002). Experience is a rich concept and the construction of experience is not straightforward. Experience tends to change over time. It emerges from the integration of perception, action, motivation, and cognition into an inseparable, meaningful whole. In the process of using products, people's requirements

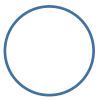
for products are constantly improving. That is to say, from the function provided by the product to the design of the product based on the human body situation, to the emphasizing the emotional experience in the process after the use of the product. People pay more attention to commercially available products, which reflect the notion of experience design as the creation of meaningful stories through a product (Hassenzahl, M., 2013). It is no exaggeration to say that emotional experience is the reason why consumers make choices when choosing products. Because the functions of competitive products have already tended to be homogeneous, and the ergonomics are becoming perfect, the only differential design comes from emotional experience. Make an example as handlebars design of a motorcycle, if the arm bends like a normal bicycle, it is just a bike ride without feeling anything. When the elbow opens a little bit out to both sides, it becomes a very different gesture and like active aggressive, transporting rider's image and feeling.

4.3 Topological Variations-Oriented Approach for Creativity Generation (TVC)

Some daily products were select to elaborate which the shapes of these products transform with topological variations. Human not only generate the new visual perception to these products, but also the products have created a new functional mechanism and the interaction between products and persons appearing in a completely new way at the same time. We take a mechanical pencil, electric fan, mobile phone, and bicycle, as examples in this study and find that the topological variations of the product shape are closely related to the radical innovation of the structure in the four products. Through the four products can deduce RPs presenting the relationship of topological variations and radical innovation. Product, human, activity, and experience the four territories visualize column. Breaking down and arranging in rows according to each section of the product, each section leads to the corresponding human body sections,

the activities of the corresponding human body sections or products, and the user experience of these sections. RPs presents a grid, and several nodes distribute in each domain. Every node present as disks visualized sets. The dotted lines as relationships between the nodes. The topological variant in visual perception (holes, connection and inside/outside), the ring present hole, the dotted line connecting a new disk from one present connection, one disk goes into/out another disk present inside/outside, Table 4.

Table 4 Three visualized symbols of topological properties in two-dimension

Prototype	Element	Connectivity	Inside/Outside
Visualized symbol			
Topological variations	Hole	New Connectivity	Outside/Inside
Visualized symbol			

The prototype of the topological variations—oriented creativity generation (TVC) show in the Figure16.

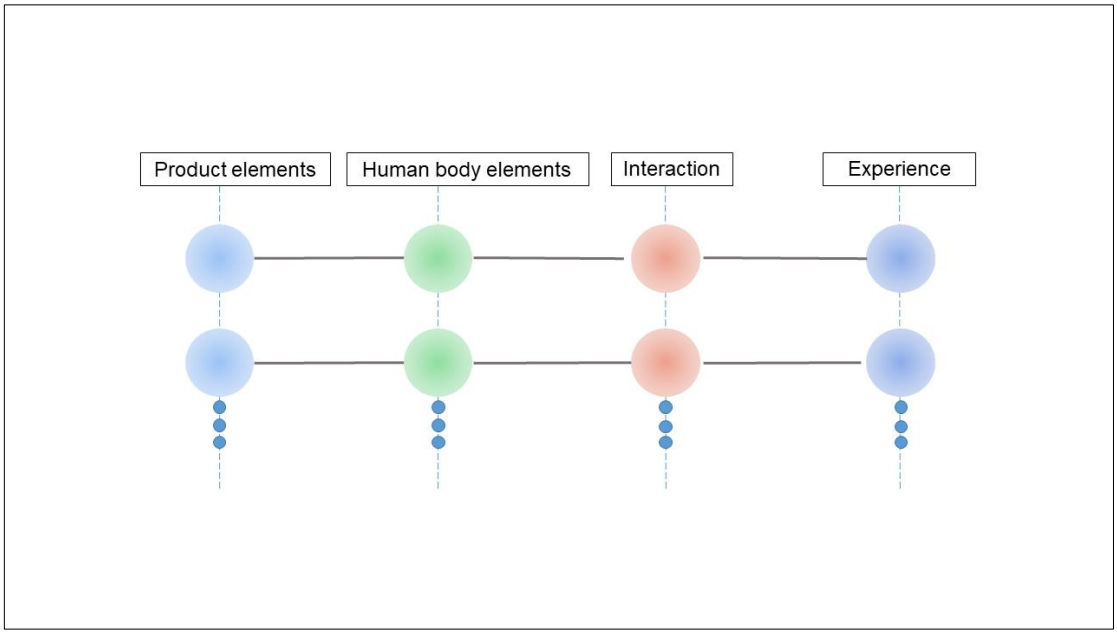


Figure 16 Topological variations—oriented creativity generation (TVC) prototype

Take an example as mechanical pencil, the typical elements are eraser cap, clip,

sleeve, grip, and cone. The corresponding TVC prototype is shown in Figure 17. We select a mechanical pencil Pilot Opt as the innovative design and modify the typical innovation, the TVC is shown in Figure18. We found that the difference belongs to topological variant between the two pictures. The most prominent innovation is that lead can be extended automatically, not by thumb pressing eraser cap, but by wrist shaking. Namely, the logical order of row, i.e. eraser cap-thumb-press-extending lead (with changing the gesture of hand). We change two relationships of the three typical ones, i.e. sleeve-hand-shake and extending lead (keep the gesture of hand).

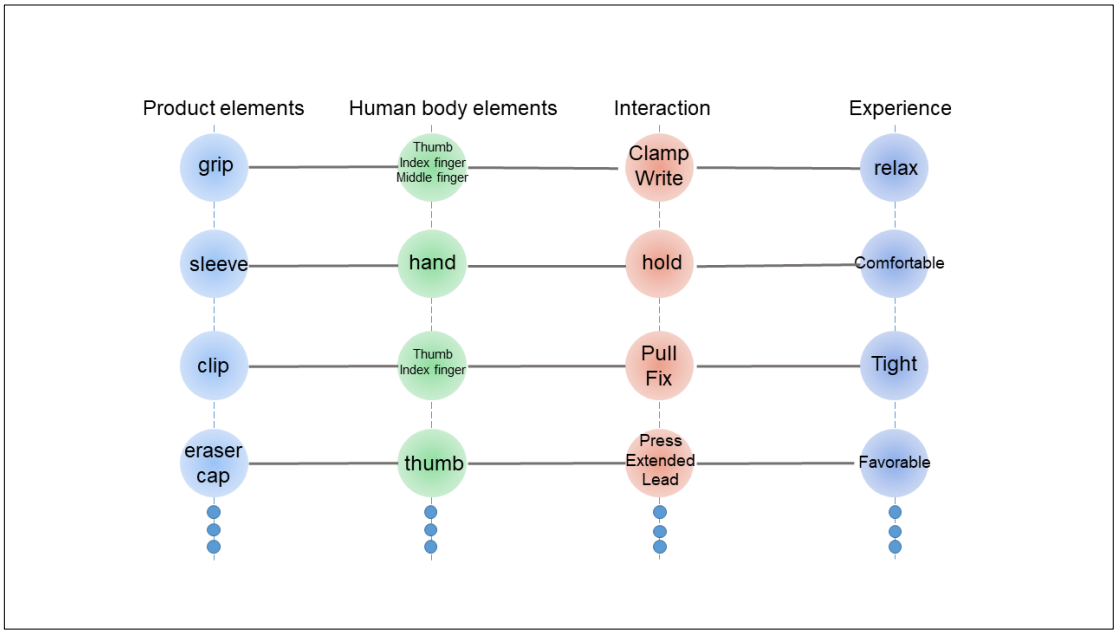


Figure 17 TVC of Mechanical pencil pilot opt prototype

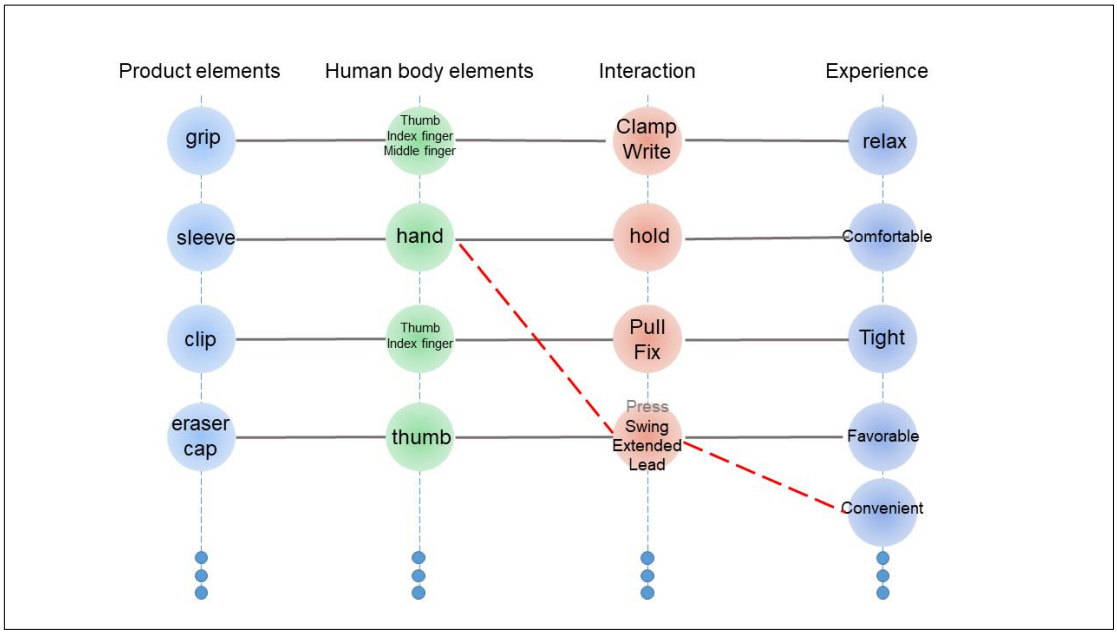


Figure 18 TVC of Mechanical pencil pilot opt

The blades are visible in traditional electric fan, according to the proximity and similarity integrate into the global field of visual perception. The blades and the shell can be presented as a disk in its TVC, Figure 19 to 20. In terms of the topological variant in visual perception, if we change the disk into the ring, or take the blades set out of the disk set, and the people still feel cool the flow air taking. Under the condition, we must find a solution that a fan blows air from a ring with no external blades. Its blades are hidden in its base. Thin high-velocity smooth airflow blows from the hole.

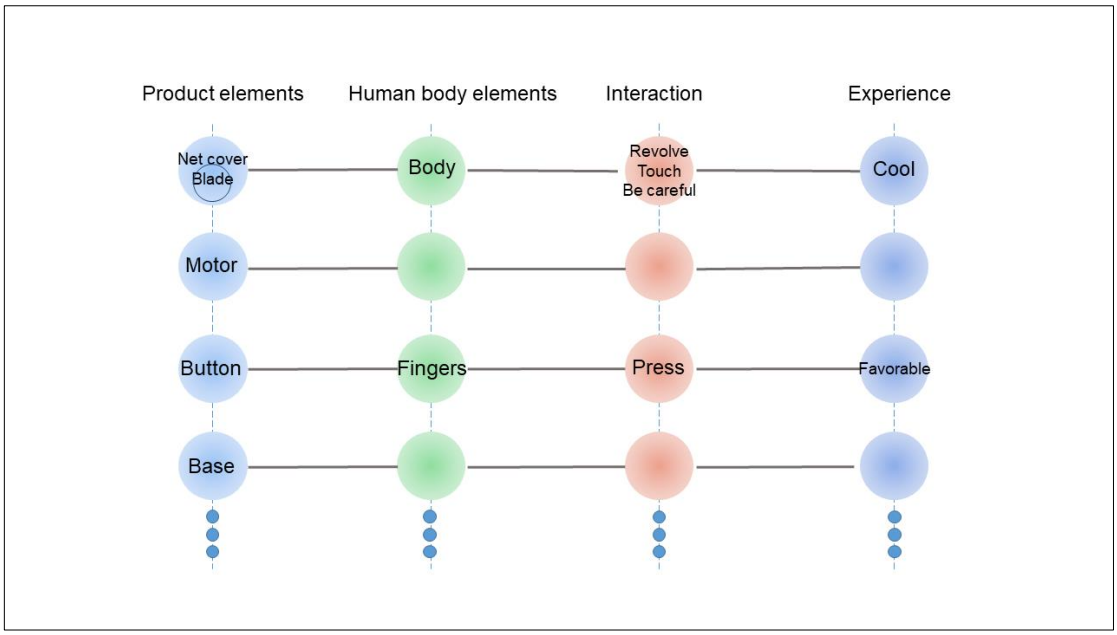


Figure 19 TVC of Traditional electric fan

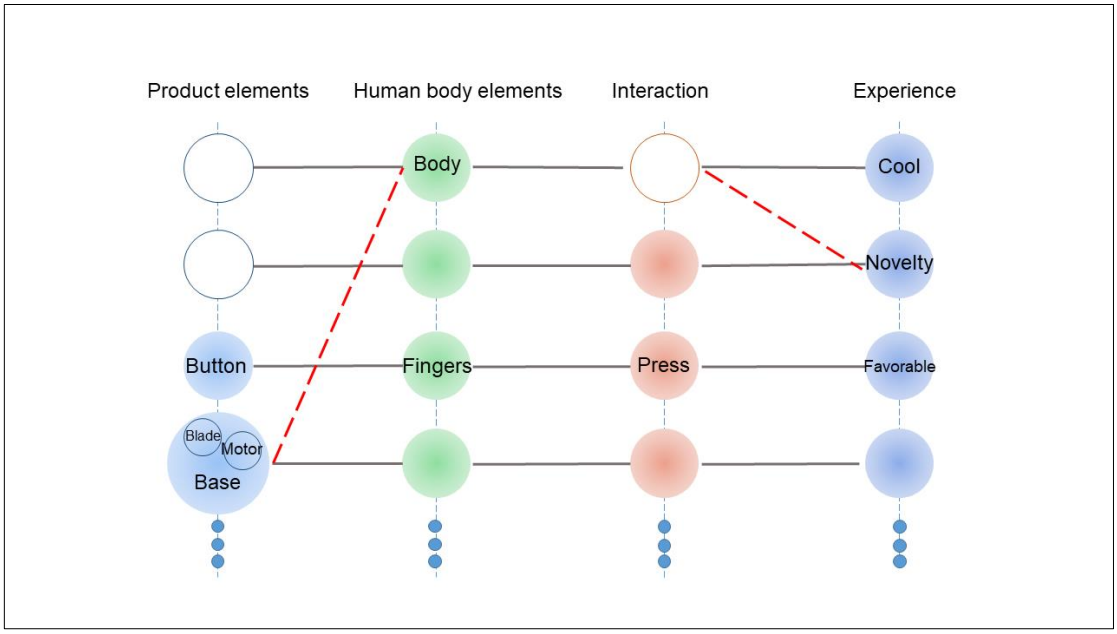


Figure 20 TVC of Bladeless fans

In the iteration of mobile phone, from mobile phone to smartphones, from the basic function is that can make and receive calls while the user is moving within a telephone area, and to multi-purpose mobile computing devices at the present days. From the three examples verified that the topological variations of the product shape are closely related to the radical innovation generated in products. This discovery is particularly evident on the mobile phone. Figure 21 shows that the screen departs the keys in the mobile phone, but the smartphones were born until the keys to go into the screen or become a hole. The physical keys disappear and present in the form of virtual ones which essence is software program. Looking back on the wide range of products of Nokia, hundreds of types were designed for consumers selecting from 1997 to 2011. However, the design of so many products failed to maintain the leading position in the world. After the second quarter of 2011, Nokia was surpassed by Apple and Samsung. Nokia's market share in the mobile phone industry declined from then on until 2014, when it completely quit the mobile phone industry. The reason is that Nokia's slow pace of reform, which is not focused on technological research and development and innovation in product and human interaction, but on repeated styling changes. From the

view of topological transformation, these changes are only at the level of Euclidean geometry. People identify the differences in terms of length and angle and these differences are distinguished difficultly. Changing the traditional interaction between mobile phone and users into the interface is built around the multi-touch screen device, including a virtual keyboard. Such a major innovation is manifested in the TVC as a topological variant, that is, the set of physical keys can be regarded as an empty set, represented as a ring, or as a set of physical keys entering the screen set in Figure 22.

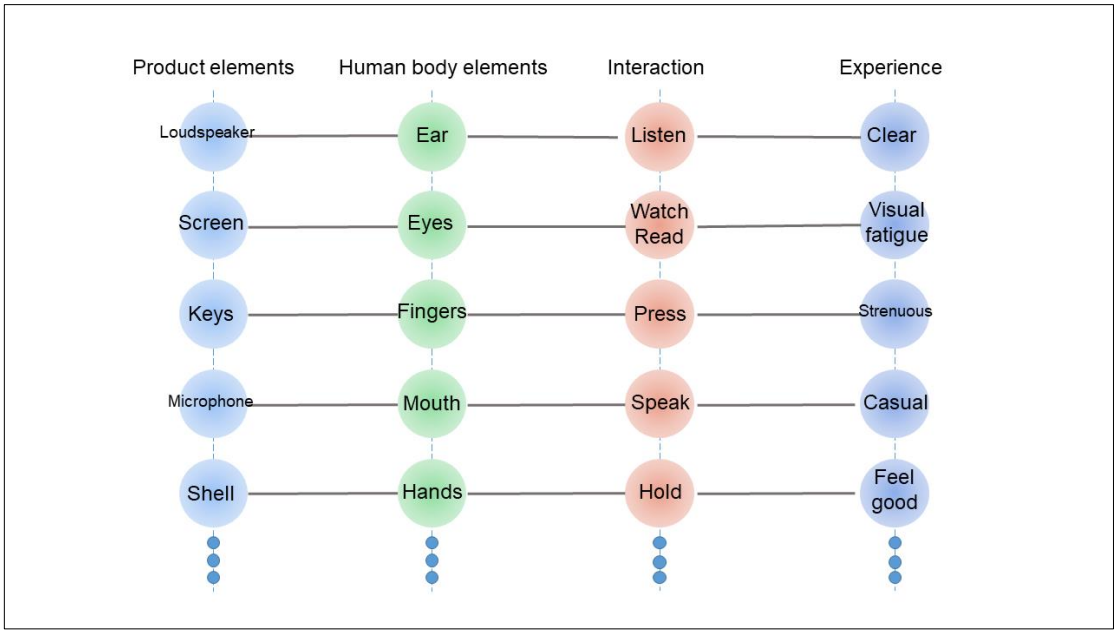


Figure 21 TVC of Traditional mobile phone

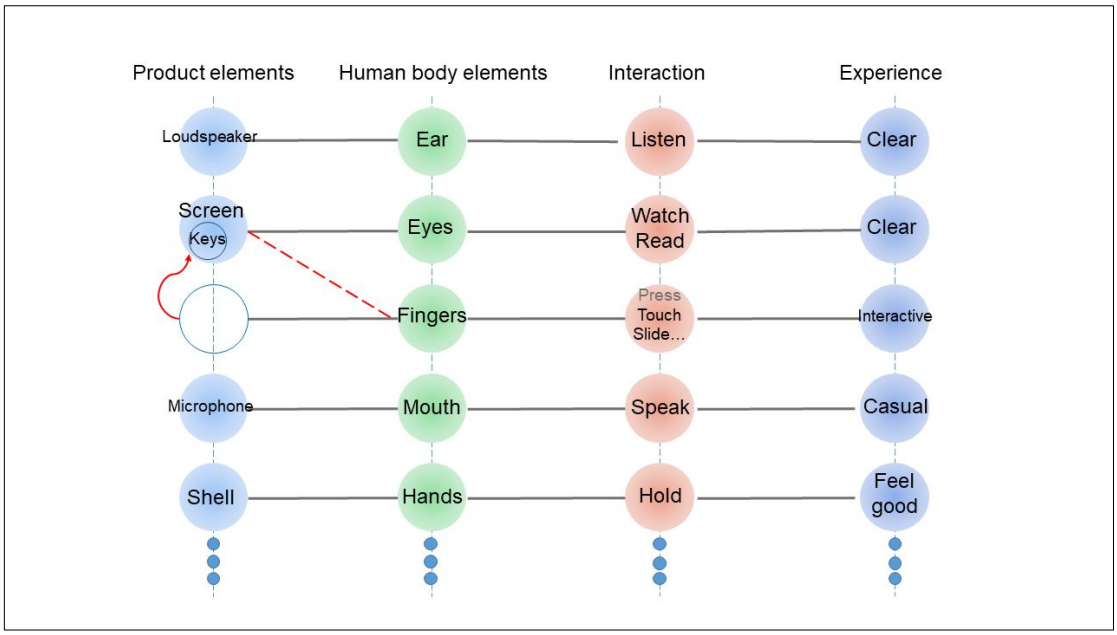


Figure 22 TVC of Smartphone

The bicycle as an example in the experiment about visual attention, it was verified a typical product in which the innovation come from topological variations. The corresponding TVC is shown in Figure 23 to 24. The topological variations belong to holes and outside/inside. We see the wheelset, including some subsets: spokes, hub, rim, tire, and valve. Wheel disk changes the hole shown as ring visually in the TVCR when subsets go out of the set, just as bicycle 2 and 8, shown as Table 2. Saddle set depart frame set in prototype bicycle, but the two sets merge into one set bicycle 2 and 8, this is outside/inside topological variant. The other two topological variations are provided in Figure21. When a new relationship is built between saddle and back, the user has a musing experiment simultaneously. If the pedal disk changes a ring (hole), a bicycle without an ankle can only rely on the feet of people to run forward. This is also a very interesting experience.

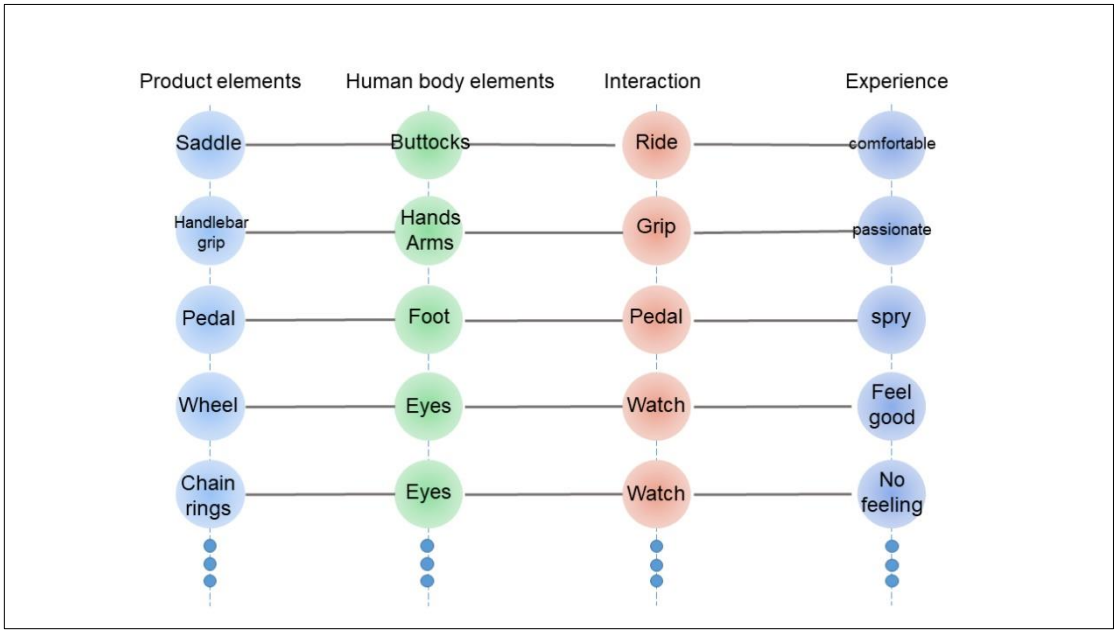


Figure 23 TVC of Prototypical bicycles

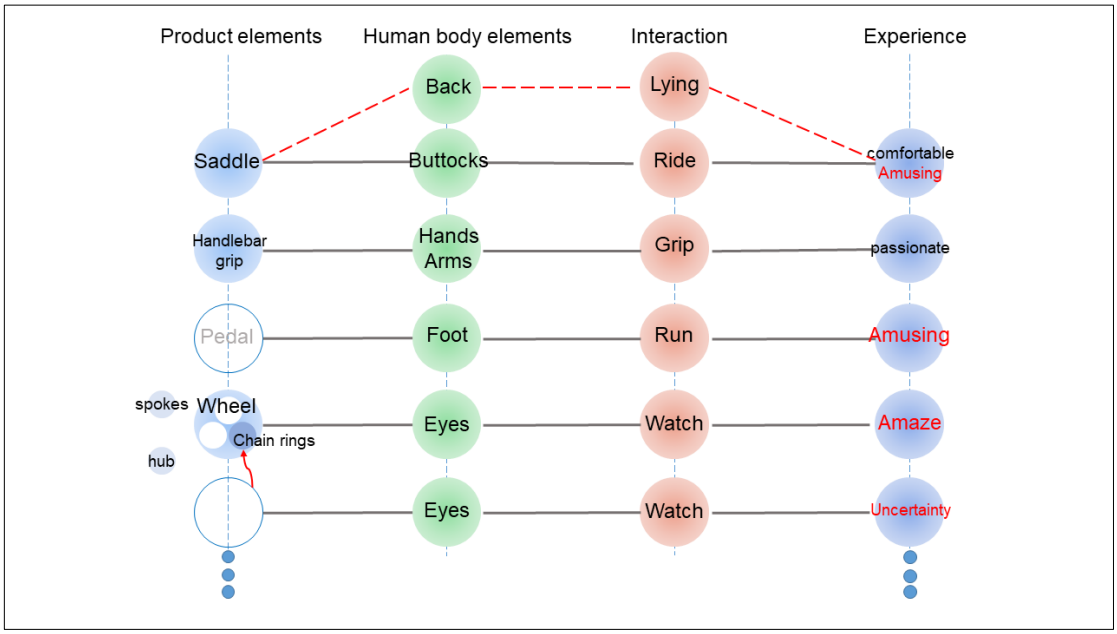


Figure 24 TVC of Navel bicycle

The most representative innovations of certain products can be illustrated in TVC, and the others do not present. Meanwhile, the changes of the plane are not continuous topological transformation but topological variations, it proposes that creative ideas can be presented through the topological variations in TVC.

4.4 Experiment design

The experiment includes two groups. The first group used topological variations to represent a visualized sheet, using it as a tool to stimulate product design creativity. The subjects of the experiment are students who study product design. By using this visualized sheet, the students' ability to creativity can be improved. The second group examines the effects of the visual sheet of this topological variation as a comparison between product design education methods and other ones.

4.4.1 Experiment objects

The participants in this experiment are students majoring in product design, and the experimental results mainly consider the contrast effect of the creative level before and after a person, rather than the contrast effect between a person and others. Everyone has

different scope and understanding of scientific and technological knowledge and different degree of application in design. In this study, the chairs were chosen as the experimental object. There are three reasons for selecting: the first is that a wide range of technical difficulties and strong flexibility of design in the chairs. The second is that the perceptions for chairs of the participants were roughly similar, with not many significant difference. In this way, the same participant can use multiple design methods to design chairs, and the effects of various methods can be compared. Test on the change of individual creativity level, the difference in the use of scientific and technological knowledge of each participant in chair innovation activities will not interfere with the experimental results. The third reason is that the chairs are especially suitable for TVC. The number of chair elements is so many corresponding to human body parts, and the corresponding relationship is obvious, shown in Table 5. Three kinds of topological variations models are widely used, which makes it easy to test the effectiveness creative model.

Table 5 The corresponding relationship between the chair and the human body

The parts of the chair	The parts of the human body
back	back
seat	buttocks
armrests	arms
legs	legs
Beam between legs	feed

4.4.2 Experiment process

1. The first group of experiments:

The first stage of the experiment is to organize 73 participants, 60 juniors and 13 postgraduates majoring in product design. The gender composition is 37 female and 36 male. After three years of specialties study, students have a certain degree of product

design expertise and skills. The design topic is to design two new chairs. Each person sends out two A3 drawings and carries out a creative design on each paper. Each person produces two sets of design plans. Pencil drawing perspective line draft, 45-degree perspective, normal visual height, can be accompanied by 200 words, time is 90 minutes. Participants are asked not to refer to existing designs, but to rely entirely on their own creativity. However, after completing the design, the lab operator asked the subject if they had referenced other designs, knowing that 12 sketches were invalid because the participants cited some designs from the network. Students themselves choose one of the more satisfactory schemes to submit, as a backup for the next stage of the experiment. Each design scheme hides the author's personal information, expressed in 101 to 161. The first 1 design represents the first experiment, and the second two digits represent the number of participants. The sample of sketches in the first stage show as Figure25.

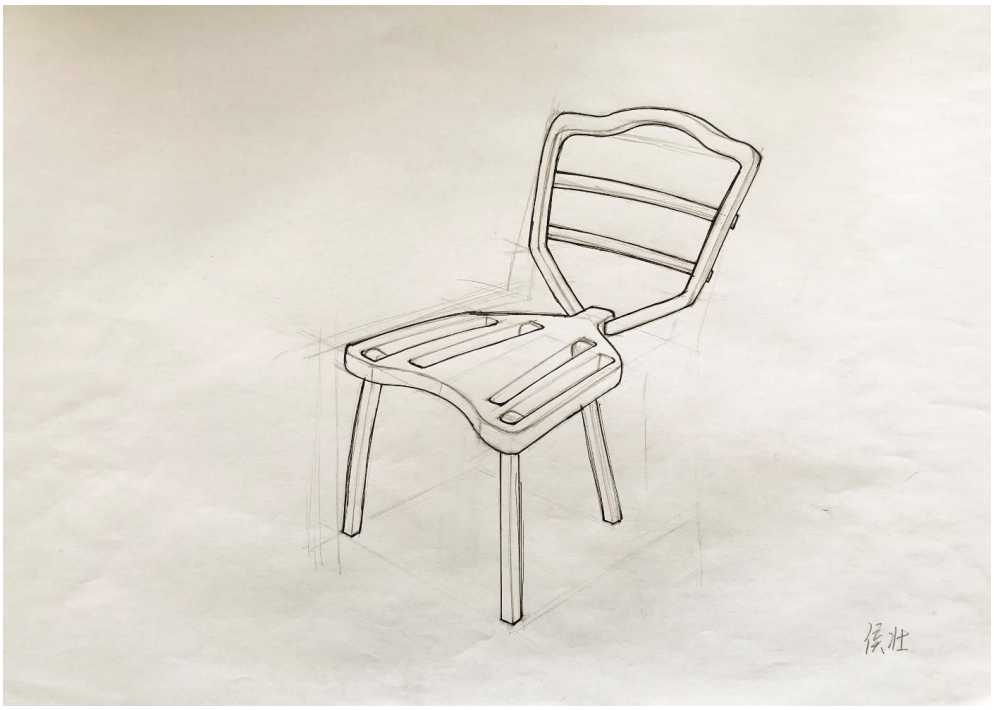


Figure 25 The sample of sketches in the first stage

After four days, the 61 people were organized to begin the second stage of the experiment. The purpose of the interval of four days is to minimize the interference between the two chair designs. First, the instructor explained the samples of the above

four products of TVC and including the three kinds of topological variations to the participants in 30 minutes. The following is the chair's TVC model as a standard reference for the experiment, Figure 26 to 29.

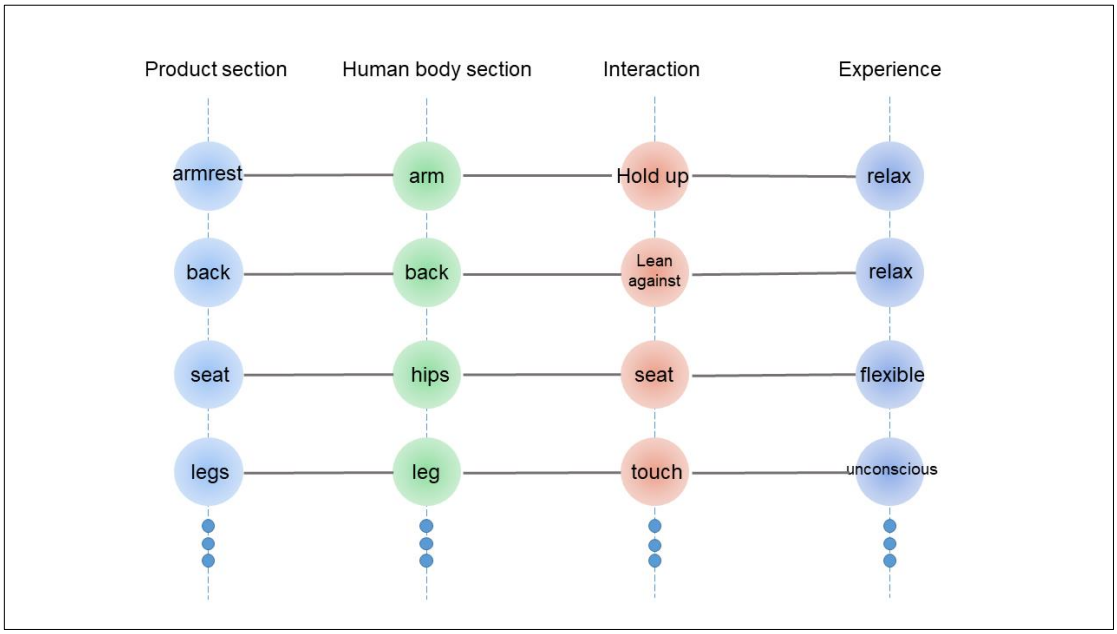


Figure 26 TVC Chair 1

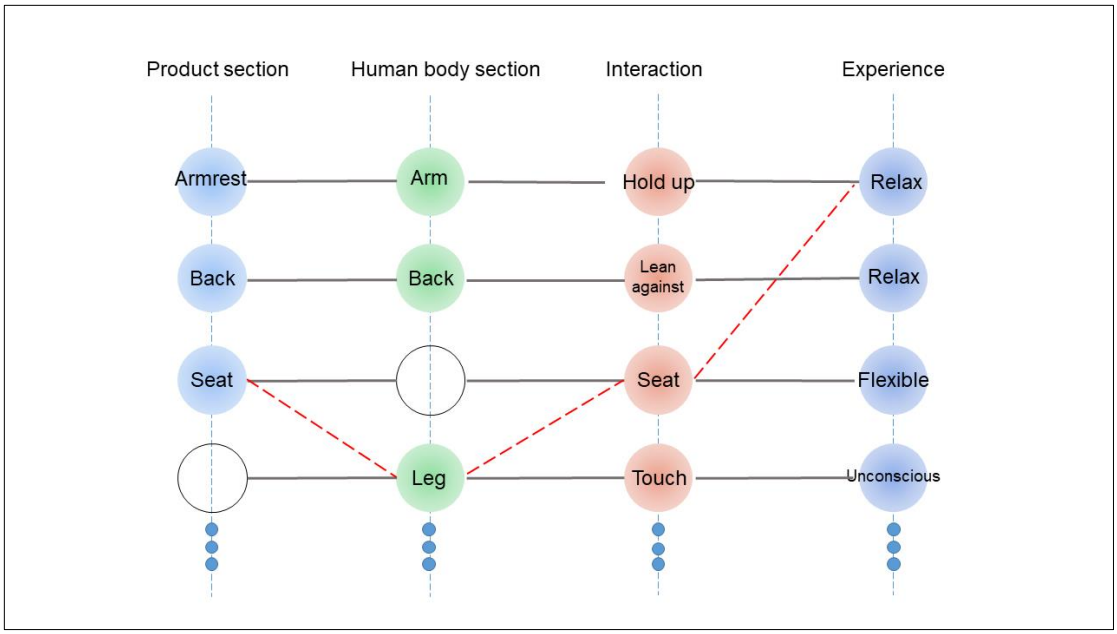


Figure 27 TVC Chair 2

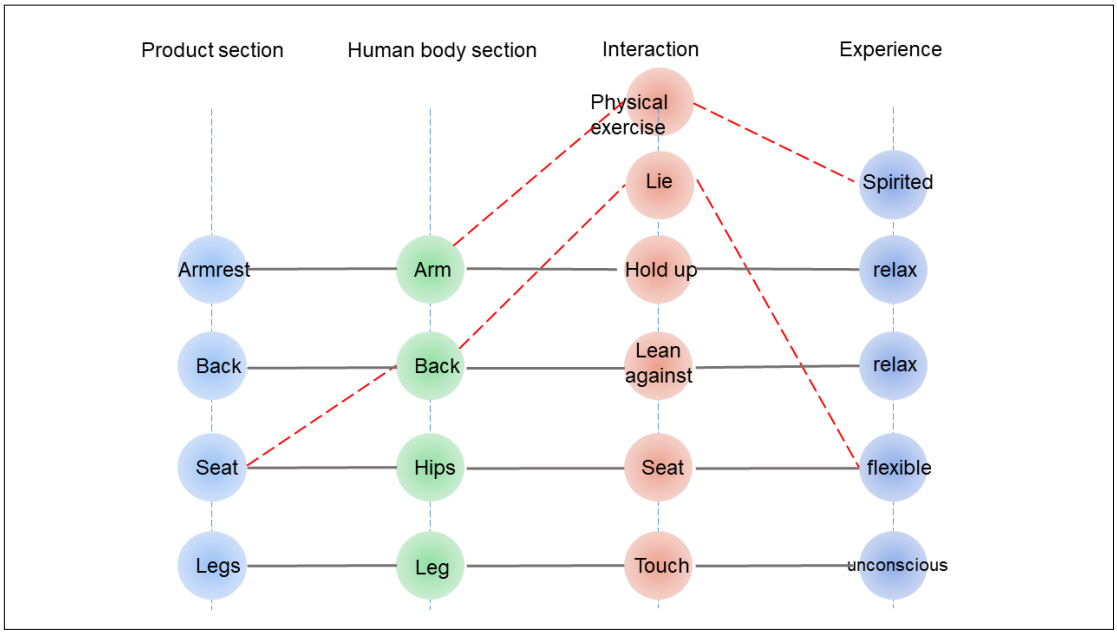


Figure 28 TVC Chair 3

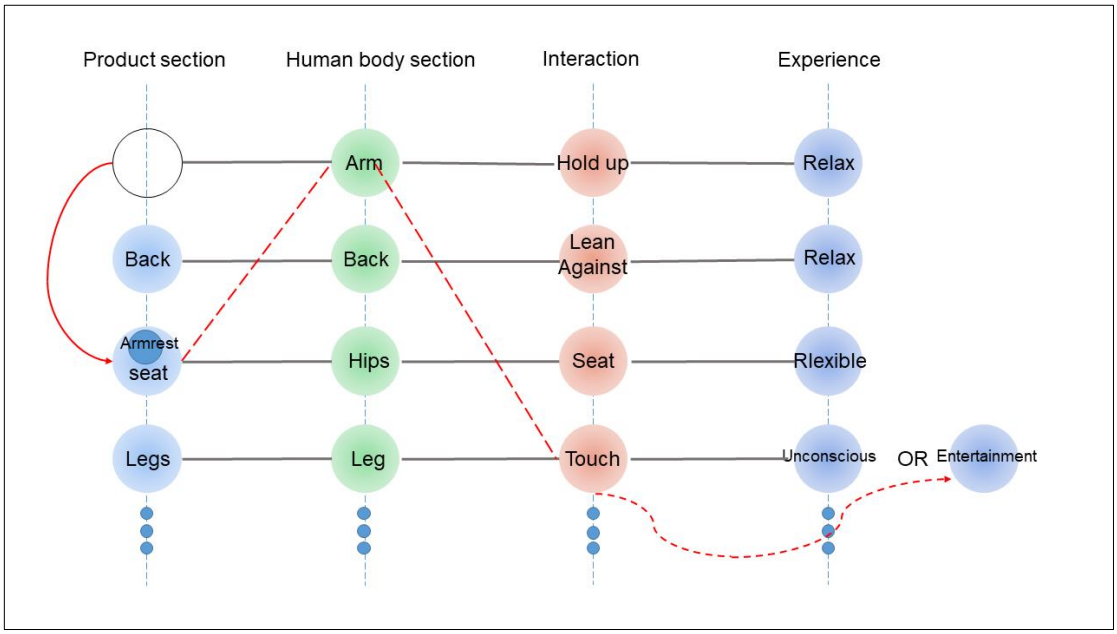


Figure 29 TVC Chair 4

Three A3 papers were sent to each participant. One is drawn TVC and the other two are to draw design sketches. Using a pencil to draw perspective sketches, 45-degree perspective, normal perspective height, with 200 words text instructions. One student came up with two designs. The design time is controlled within 90 minutes. Students themselves choose one of the more satisfactory schemes and submit to assistants, as a backup for the next stage of the experiment. The sample of sketches in the second stage show as Figure 30.

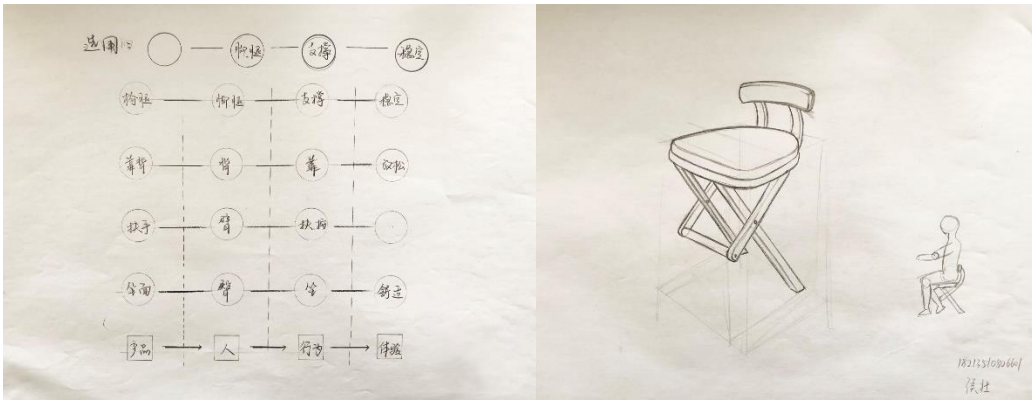


Figure 30 The sample of sketches in the second stage

The third stage of the experiment is to organize 45 other product design students to score the two design, using the 7-point Likert scale. Because it is the evaluation of the design, the subjectivity of the evaluation is strong, so this graded evaluation method is adopted. The 45 scores of each participant were taken as the mean. The two times data group respectively named First1 and Second1. The score form is shown in Table 6.

Table 6 The score form

Number	7-point scale score							Remarks
101 （201）	○ 1 Very dissatisfied	○ 2 dissatisfied	○ 3 less dissatisfied	○ 4 average	○ 5 less satisfied	○ 6 satisfied	○ 7 very satisfied	
102 （202）	○ 1 Very dissatisfied	○ 2 dissatisfied	○ 3 less dissatisfied	○ 4 average	○ 5 less satisfied	○ 6 satisfied	○ 7 very satisfied	
…								
161 （261）	○ 1 Very dissatisfied	○ 2 dissatisfied	○ 3 less dissatisfied	○ 4 average	○ 5 less satisfied	○ 6 satisfied	○ 7 very satisfied	

Use Kolmogorov-Smirnov to test First1 and Second1, the two groups of data are non-normally distributed, $p < 0.001$. Two related samples get significant differences in scores between the First1 and Second1 two groups, $z = -3.140$, $p=0.002$, and the score using TVC are higher than those did not use (First1, median=3.29; Second1, median=4.91). Since the two sets of data are non-normally distributed, we compare

them with the median.

2. The second group of experiments:

Forty-five students of the same grade in product specialty were organized and these participants are different from those in the previous stage. The number of females is 23 and the male is 22. In the first stage, every 15 participants randomly are a group, choose one of the following design methods to carry out innovative chair design: Visualization, Analogies, and SCAMPER. The contents and rules are the same as the first stage of the first group of experiments in the stage.

After four days, the 45 participants were organized to begin the second stage experiment. In the stage, the contents and rules are the same as the second stage of the first group of experiment.

The third stage of the experiment is to organize 45 other students majoring product design to score the two design schemes, using the 7-point Likert scale. The 45 scores of each participant were taken as the mean. The two times data groups respectively named First2 and Second2, Visualization and TVC1, Analogies and TVC2, SCAMPER and TVC3. Statistical analysis of the data is shown in Table 7.

Table 7 Statistical analysis of the data

Data group	Median	Normal distribution	Two related samples test
First2, Second2	median=3.18, edian=5.07	$p<0.001$, $p<0.001$	z = -3.324, p=0.001
Visualization, TVC1	median=3.02, edian=5.80	p=0.035, $p<0.001$	z = -1.988, p=0.047
Analogies, TVC2	median=3.84, edian=5.04	p=0.034, p=0.012	z = -2.102, p=0.036
SCAMPER, TVC3	median=3.16, edian=5.07	p=0.008, p=0.004	z = -2.158, p=0.031

4.5 Summary

In the first group of experiments, the creativity of participants improved significantly from the overall situation. In the second group of experiments, TVC has some significant advantages over other design methods. From the beginning of this experiment, that is, when TVC was taught to students, students initially showed a more

acceptable attitude, which mainly benefited from two points. Firstly, by taking several creative products that already exist in our lives as examples, this study analyses the reasons for their successful creativity sums up the commonalities of these successes and then makes assumptions about these commonalities. In fact, these product cases have been deeply rooted in the hearts of students, and students often think about the reasons why they make success. when they find that these reasons seem to have similarities to their own reasons for this success, they have a strong curiosity about the seemingly unrelated ideas are based on the topological variant. Once the creative model of topological variant is mastered well, students think that more high-quality ideas will be created. Because of the topological variation made on the visual sheet, the product presented a qualitative change, a new function or a new experience.

Another point is that the whole operation process of TVC is represented by visual symbols. All creative ideas were designated symbols. It does not require too much effort to remember the correspondence between symbols and creativity. These visual symbols have a strong instructional operation. Follow the instructions and naturally get the results. According to the results, the students think about the path and method of realization. This reverse derivation can reduce a lot of mental work compared with direct derivation. To be exact, it can reduce the thinking of analyzing and choosing a large number of uncertain problems.

Chapter 5

Case study analysis and results

Content

Chapter 5. Case study analysis and results

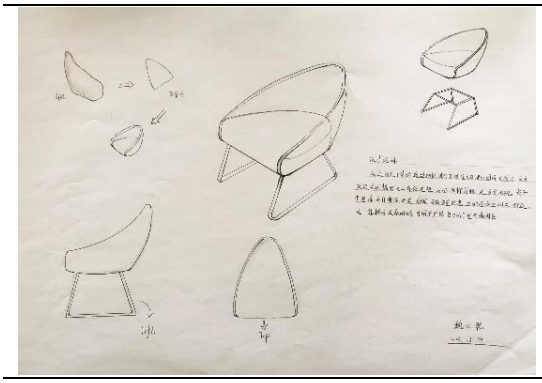
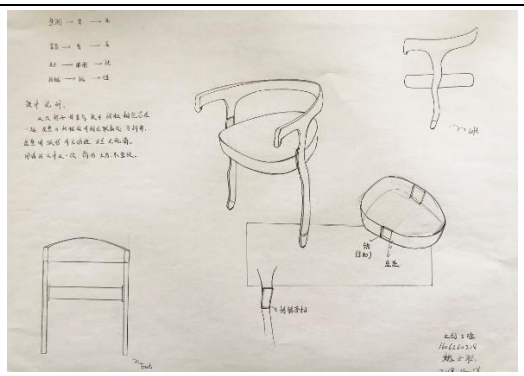
From the statistical results of the experimental data, it can be seen that the participants were significantly affected by TVC. The quality of the design creativity of the participants has been greatly improved, and the personal design ability has also been significantly improved.

5.1 General features of the results

The creative point of design 108 is in the aspect of form in the first creativity. The original source of form is the shape of Blue mussel, from which the overall shape of seat and backrest is derived. This design method is similar to Analogies. These subjects are juniors and postgraduates. In the previous professional courses, they have learned a variety of product design methods mentioned in 2.1. The blue mussels are used to change the shape of the chair to achieve the similarity of the shape of the chair and the blue mussel. Analogies, as a marine organism, is composed of curves and surfaces. The overall shape has a certain degree of curvature aesthetic feeling. At the same time, it has texture on the surface. It is similar to the pattern of annual rings. It has an orderly composition. People tend to have the beauty of orderly things, which will attract people's attention. However, although this kind of creativity can arouse people's attention, it is difficult to convince people to decide what to own. Because the creative point in the product form aesthetics, the shape aesthetic innovation is more in the quantitative level, thousands of shape aesthetic creativity, but only to leave a variety of shapes for people, it is difficult to achieve the reflective design. The second design, the creative point is that the structure of the chair has been greatly subverted, that is, the customary four-legged or three-legged chair, actually designed into a two-legged chair. From the use process of TVC, we can see that using topological variant inside, the human legs are moved to the chair legs, and the human legs also bear the support

function of the chair legs. This idea will make the viewer feel unrealistic, it is unrealistic if the human leg can bear the function of a chair leg unless it is used on special occasions. The shape of this recreational chair is obviously not suitable for this kind of creativity. However, the advantage of TVC is that it must get a new result by operating according to instructions. Then, in order to realize this result, we should think about and adopt appropriate methods and means. This is the process “how”, which emphasizes logic deduction more than process “what”, and “what” is to build new logic. Then, the two-legged recreational chair can be completely achieved by technical means, and the balancing car with two wheels provides favorable evidence for achieving this goal. The automatic balance system controlled by a microcomputer is installed in the chair, which not only supports the human body but also enables the user to control the angle of the chair freely so as to make the body more comfortable. Here we will also introduce participant of design 108. According to the three years of professional achievement, this participant's professional ability is not very strong, and it is not prominent in the whole grade. But in this experiment, the improvement effect is the most obvious, Table 8.

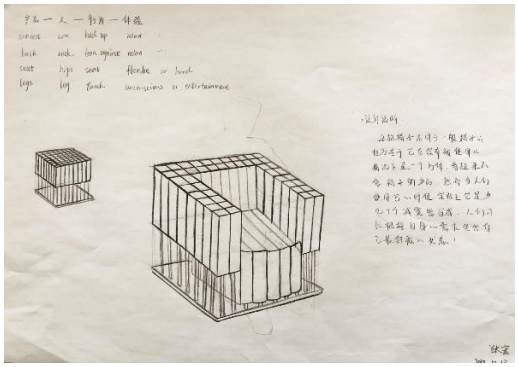
Table 8 Design 108

Free Design 108-1	TVC Design 108-2
	
mean=3.09	mean=5.93

The originality of the first scheme of 118 is also in the aspect of morphological transformation. The original source is the shell shape which derived the shape of the chair back. The structure of the chair is the same as that of the normal chair. The comfort of human beings is thought of in material. Through the first design, we can judge that

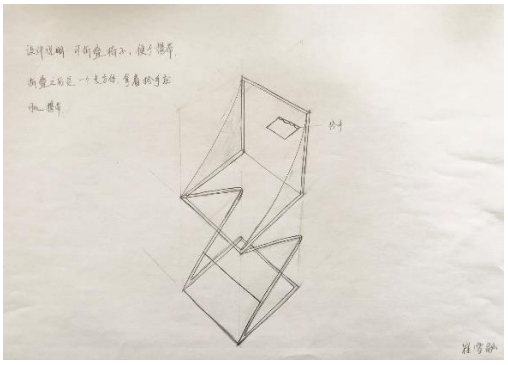
the participant's innovative thinking is not good. However, it is clear from the second plan that participants broke through the existing logic of thinking and completely broke the stereotype structure of chairs in their own minds. All parts of the chair are fused together, and the chair constantly adjusts its shape according to the sitting position of the person to suit the posture of the person automatically. The innovative thinking of participant 118 improved significantly, Table 9.

Table 9 Design 118

Free Design 118-1	TVC Design 118-2
	
mean=4.00	mean=5.87

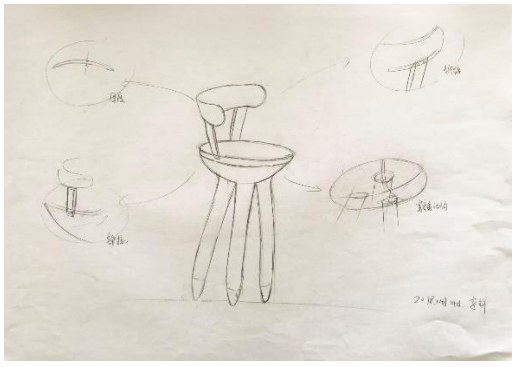
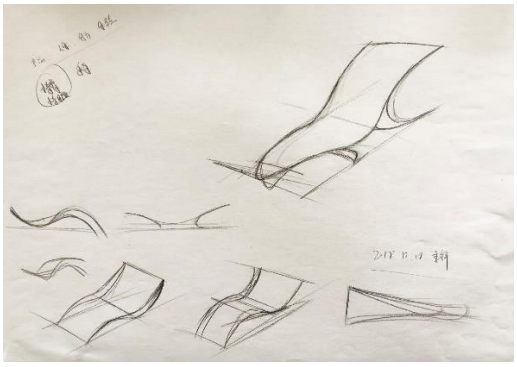
The creative point of the first design of 136 is the aspect of the structure. The chair and stool can transform each other accompany the structure changing. The second design is also creativity in structure. The chair can be folded to reduce the volume, and then easy to carry. The creative level of the two designs is basically the same. However, the two scores are both low, reflecting that the two designs are not excellent. Moreover, the second design looks ambiguous, indicating that the participant did not yet understand TVC, Table 10.

Table 10 Design 136

Free Design 136-1	TVC Design 136-2
	
mean=3.07	mean=3.20

The creative point of the first creative project of 137 focuses on the use of the environment of chairs. The design is a high chair, which has beautiful posture, harmonious local and overall collocation, and has a greater possibility of commodity transformation. The creative point of the second design is also to pay attention to the use of the environment of chairs, which is a beach chair. From participants' TVC, it can be seen that he treats the armrest set according to the pattern of the topological variant hole, and then integrates the seat, back, and leg according to the topological variant inside, which integrates morphologically. After the chair's shape is completed, which is suitable for the use of a beach chair, Table 11.

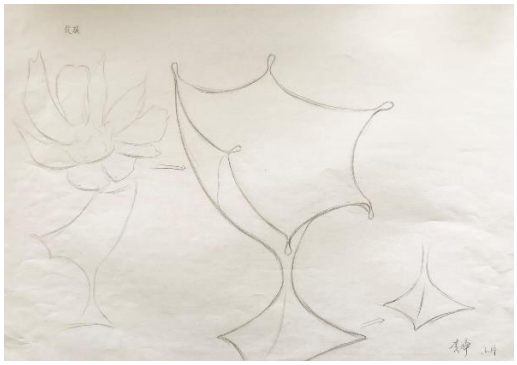
Table 11 Design 137

Free Design 137-1	TVC Design 137-2
	
mean=3.18	mean=3.24

Take 110 as a representative case to analyze the participant who scored higher in the first time than the second time. The first project was based on the theme of

"blooming". The shape of the chair was like blooming flowers. All parts of the chair were integrated, and the shape of the flower and the shape of the chair were naturally transformed, without an uncomfortable feeling. On the contrary, the second project has a certain degree of integration, but the overall shape of the chair is similar to the chair in the market, so the score of the second is lower than the first project, Table 12.

Table 12 Design 110

Free Design 110-1	TVC Design 110-2
	
mean=5.09	mean=2.22

5.2 Analysis of the specific case study

The dominant characteristics of TVC were analyzed by specific experimental cases recorded below. This process takes less time to teach the methods used in the model. The teaching process set to 30 minutes. By explaining the relationship between product shape innovation and topological variations through existing relevant cases, students are quickly inspired to receive these findings. By transforming the visual features of three kinds of topological variations into more appropriate visual symbols, participants can easily remember the topological variations. RPs itself is a plane that visualizes the process of thinking about things, environments, and relationships. The symbols of the three topological variations are nested in PPs, and the combination is natural. The participants do not feel far-fetched.

It takes less time to generate innovative ideas. Every operation of TVC can be an idea, but this idea is mainly evaluated by realizability and non-realizability, not by

meaningfulness and non-significance. It can be said that the ideas created by TVC can be applied very high, through contemporary technology, new materials, production processes and so on. Comparing TVC with Visualization, Analogies, and SCAMPER, the three methods take longer to get ideas from start to finish. The experimental exhausting time show as Table 13. In many design methods, brainstorming takes a very long time. Brainstorming is actually a process of gathering people's collective ideas and gradually screening out innovative ones. Collection and screening take a long time, even up to about two weeks.

Table 13 Time required to use the design method

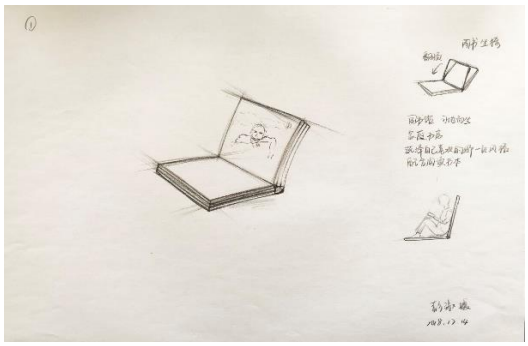
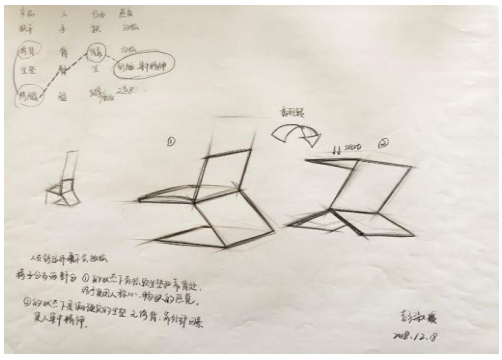
Design Method	Duration (mean)
Visualization	18mins
Analogies	20mins
SCAMPER	25mins
TVC	15mins

TVC is divided into four territories: product, human, activity, and experience. Four fields involve almost all aspects of product design. In these four territories, because of the establishment of new relationships, the creativity generated is bound to be related to all aspects of product design. Visualization is to show the vision of the future in the form of situational stories, to think about what to draw, to give full play to the imagination, without any burden of thought. However, one's thinking is biased and limited. It is impossible to achieve openness completely. Therefore, there must be omissions. Of course, visualization also generates many fantastic ideas, but whether these ideas have practical significance is uncertain. The foundation of TVC is to list the existing products, users, activities of users or product and experiences. The new links established are realistic and realizable. Even if new projects can be added in the four fields, it is also a new project based on reality, and the links drawn from new projects are equally achievable. Visualization solves specific problems by sketching the story and develops ideas along with the logic of a problem. This design method is commonly

used by students. It is very effective to find a solution by sketching the final goal. Its advantage is to show the problem to the final goal through the sketches, so finding the solution is very effective, but there is also no solution. The solution does not solve the underlying problem, resulting in wasted resources. The following three groups of cases are comparisons between TVC and visualization. Design 220 and design 228 performed better in TVC and design 222 performed better in Visualizations. We make a detailed analysis.

Design 220-1 depicts a chair for use by readers in a library. Participant imagines the library as a fairy tale world of books. It seems that everything is a book, and the chair is naturally a book, and the corresponding book chair can be selected according to the preference of the individual reader for which type of book. In design 220-2, the chair is not only a book but also a lot of sitting postures for the reader to choose. Although the shape of the chair and the book are quite different, the structure and function of the book are fully combined, instead of the form of the book is used directly and hard. This is the reason why design 220-2 is better than design 220-1, Table 14.

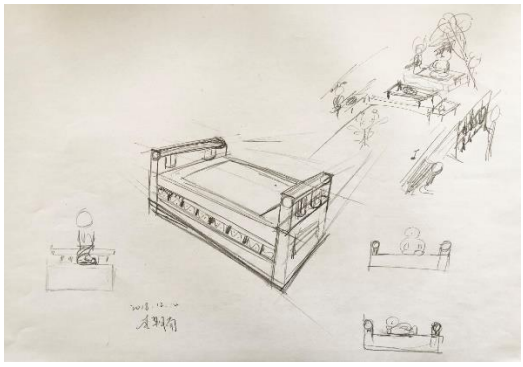
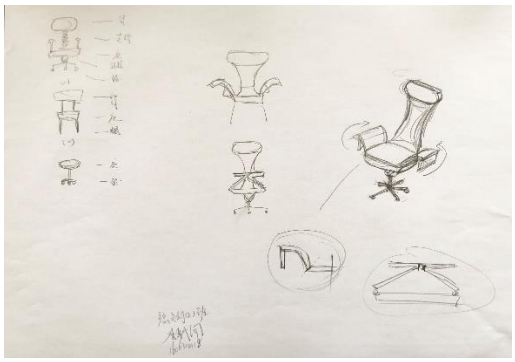
Table 14 Design 220

Visualization Design 220-1	TVC Design 220-2
	
mean=3.18	mean=5.91

Design 228-1 depicts an emperor sitting on a chair. The idea is to imagine himself as an emperor, and thus the form that the program shows. The design idea in design 228-2 lies in the structure, the armrests, and the seat are linked together, and when certain special circumstances are encountered, the user can adopt the mode of sitting on

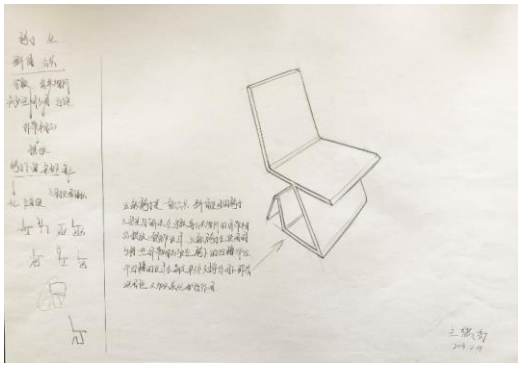
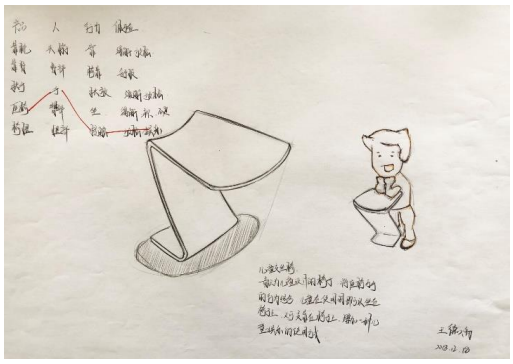
the armrests. Although the first program provides a wonderful scene for the viewer, this kind of impractical is unrealistic and far away from our real life. Design 228-2 is highly practical. This is the reason why design 228-2 is better than design 228-1, Table 15.

Table 15 Design 228

Visualization Design 228-1	TVC Design 228-2
	
mean=2.18	mean=5.82

Design 222−1 is to combine the shape and storage functions to solve the problem of item placement. Design 222−2 is the child chair. Combine the seat and armrests to expand the way children use them. However, there are certain security risks in this program. The reason may be why design 222−1 is better than design 222−2. Table 16.

Table 16 Design 222

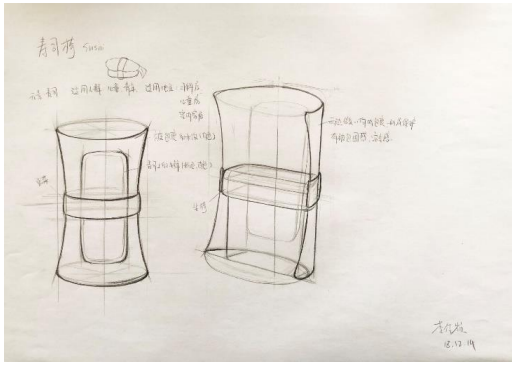
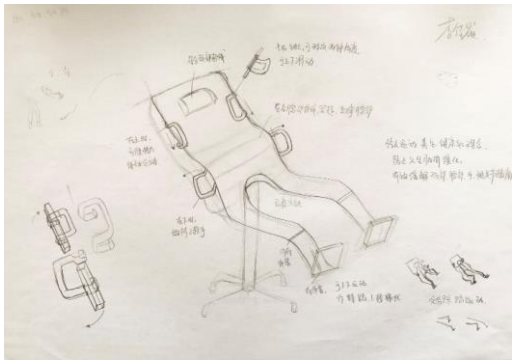
Visualization Design 222-1	TVC Design 222-2
	
mean=5.96	mean=3.93

Analogies are the most common design method for students, and the reasons are related to the thinking methods of analogies. At the beginning of children's cognitive development, parents will use analogies to help children recognize abstract things and problems. As an adult, when performing advanced brain activities like creativity, you

still choose frequently or habitually choose analogies. The following three groups of cases are comparisons between TVC and analogies. The two groups of TVC performed better and a group of analogies performed better. We do a detailed analysis.

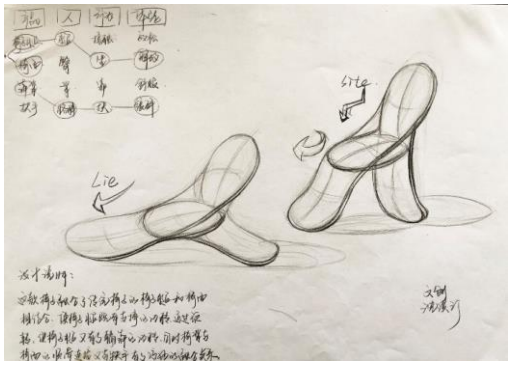
Design 209-1 replaced a chair with the sushi and compared the meaning of the sushi package to the safety and comfort of the chair. However, the shape of the sushi was slightly inappropriate, and the shape of the chair was somewhat dull. Design 209-2 creates a new user experience by changing the relationship between the various parts of the chair. The user can rest on the chair and do simple physical activities. Everyone can take advantage of the imagery generated by analogies, but TVC creates new connections in familiar things, which is recognized by many people, Table 17.

Table 17 Design 209

Analogy Design 209-1	TVC Design 209-2
	
mean=3.13	mean=5.84

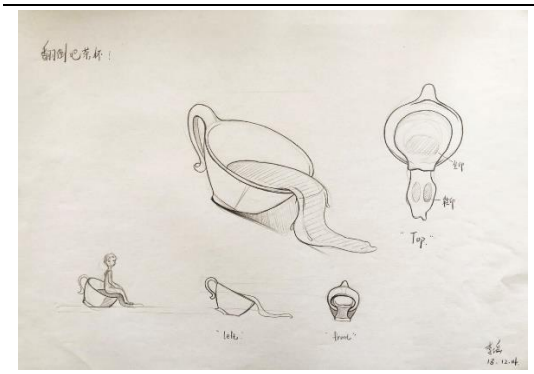
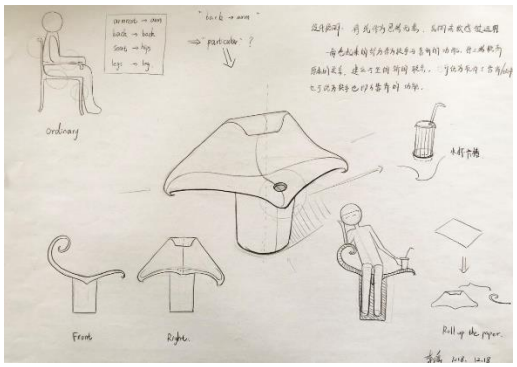
Design 219-1 looks like a smile, and sitting in a chair is like sitting in a smile. The storage drawer is like a tooth that is exposed when smiling, and the drawer is opened like a tongue that spits out when smiling. Design 219-2 can be seated or lying by changing the posture of the chair. The overall shape is very beautiful, and the various postures do not destroy the beauty of the overall shape, so it is favored by most people, Table 18.

Table 18 Design 219

Analogy Design 219-1	TVC Design 219-2
	
mean=3.84	mean=5.91

Design 201-1 transforms the shape of the chair into a cup that is spilling coffee. It is difficult for people to see this moment in normal times, and this rare form can be used in the shape of a chair, which really brings novelty. The experience of design 201-2 is based on TVC. Applying, trying to change the connection between the various parts of the chair, but the appearance of the chair is quite normal compared to design 201-1, Table 19.

Table 19 Design 201

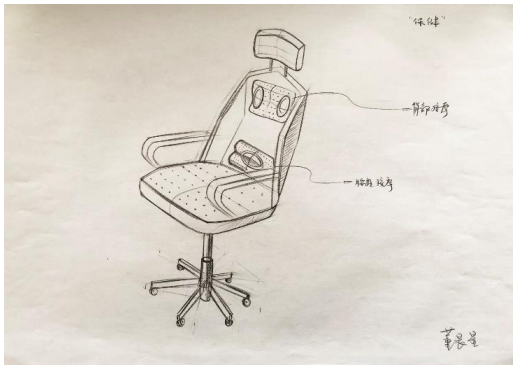
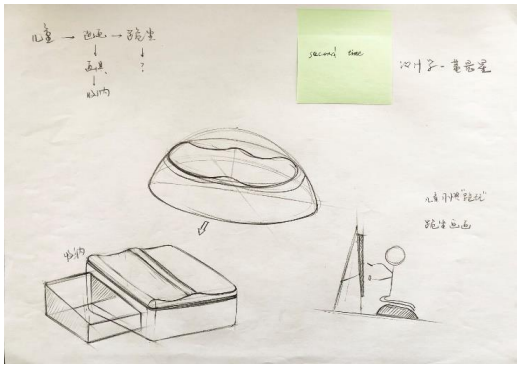
Analogy Design 201-1	TVC Design 201-2
	
mean=5.84	mean=3.16

SCAMPER is similar to TVC in that it is instructive rather than heuristic. According to these instructions, “substitute, combine, adapt, magnify or minify, put to other uses, eliminate or elaborate and rearrange or reverse”, certain ideas will be generated. However, SCAMPER takes slightly longer than the result of the directness of TVC. Certain instructions in SCAMPER are themselves making quantitative changes, such

as magnify or minify, eliminate or elaborate. Moreover, rearrange or reverse, a pair of instructions, is likely to produce a qualitative change in creativity.

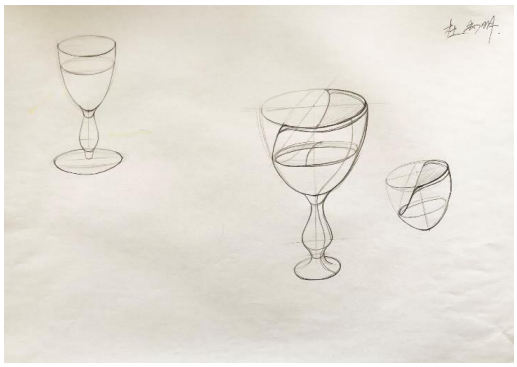
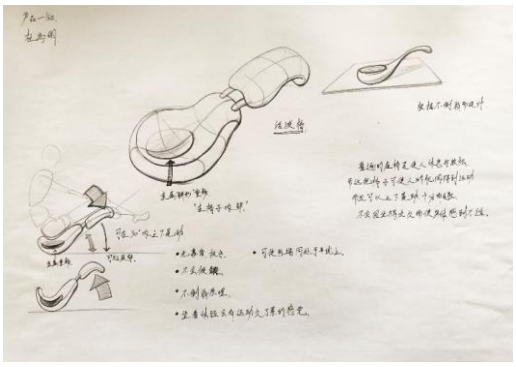
Design 241-1 combines the form of an office chair and a massage chair. There are a lot of office chairs and extra health products designed for office workers on the market, and this kind of design is very mature. Design 241-2 is a seat designed for children's paintings. It is based on children's activity rules and seats for the buttocks and calves, cleverly combining sitting and squatting Table 20.

Table 20 Design 241

SCAMPER Design 241-1	TVC Design 241-2
	
mean=2.16	mean=5.29

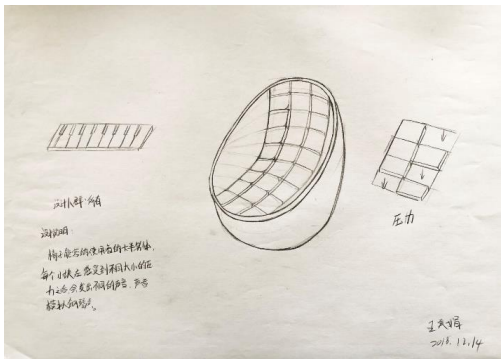
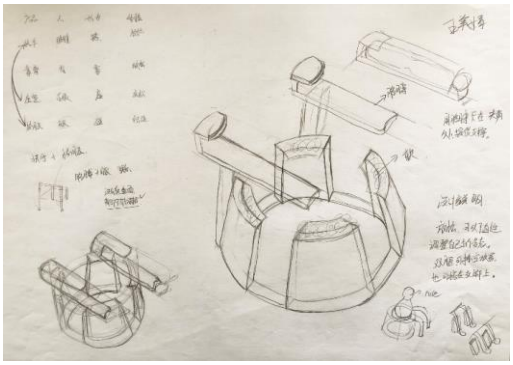
Design 217-1 is an enlarged wine glass and then adjusted the shape to form the chair. When the wine glass is enlarged, it does not require too much design means, it can serve as a chair. The idea of design 217-2 is to connect the buttocks and back to the seat, and when people are in these two positions, they naturally enter two states: relax and exercise. The technical support for achieving exercise is based on the center of the spoon gravity. Design 217-2 has been recognized by more people, Table 21.

Table 21 Design 217

SCAMPER Design 217-1	TVC Design 217-2
	
mean=3.22	mean=4.87

Design 205-1 connects the chair to the piano. The seat and back are made up of multiple modules. Each module is equivalent to a piano key. When people sit on it, somewhere in the body will trigger a certain module, along with the sound, adds fun, and the relationship between the person and the chair is more abundant. Design 205-2 is functionally related to the armrests, the seat, and the legs, but the new connection is confusing because the participant did not understand the TVC, or the participant does not complete the new connection perfectly, and the experiment ends. The score of design 205-2 is lower than design 205-1, Table 22.

Table 22 Design 205

SCAMPER Design 205-1	TVC Design 205-2
	
mean=4.91	mean=3.20

Most of the innovative ideas focus on making changes in the nature of the original product; the biggest feature of TVC is that it is based on the topological properties and variations. As long as topological variations occur, the product form, function or

performance will definitely change qualitatively. The probability that the ideas generated by visualization, analogies, and SCAMPER are qualitatively variable is not very high. Visualization is the visualization of future scenarios. Whether this future scenario is a qualitative change in the current life depends on the specific content. Analogies are the most commonly used innovative thinking methods, so the creative similarity is relatively high. SCAMPER does create a lot of new ideas, but it takes a lot of time to memorize each of the methods. The advantage of TVC is that it is prescriptive and easy to remember. Participants can quickly get ideas under the guidance of instructions.

5.3 Methodology for TVC

The greatest advantage of TVC is easy to understand, that is, to visualize the development process of product design thinking in the form of visualized sheet. The topological variations of the visualized sheet lead to innovation in product form. Even if there are no topological variations in product form, there is a new relationship between the function, performance, and other elements of the product. It is worth emphasizing that visualizing the development process of product design thinking in the form of RPs is the core content of creative thinking, establishing new links between elements. As long as there are new connections among the elements, the system constructed as these elements will inevitably change. The changes are manifested in the elements of a territory, a part of the product, the human, activity, and experience.

5.3.1 New connectivity

In nature, elements can form a variety of new substances through combination, and the idea of planning can also be generated from element combination, that is, designers can obtain new ideas by studying the combination of various elements. Designers should not stick to conventions. They must constantly try and speculate on the possibilities of

various combinations and obtain innovative ideas with the new value. The combination of elements is not simple addition, but a creation based on the original. The elements that can produce creativity are all-encompassing. They can be practical or abstract. They can be real or imaginary. Coke cups can be eaten, ice cream can be fried, exterior wall paint can be drinkable, and so on. They are all combinations of elements that transcend common thinking habits and directions.

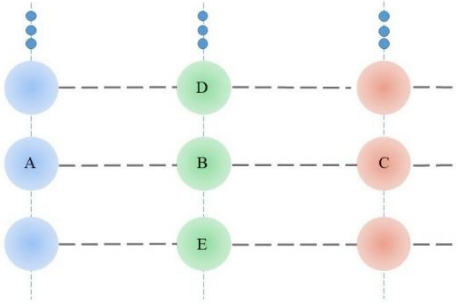
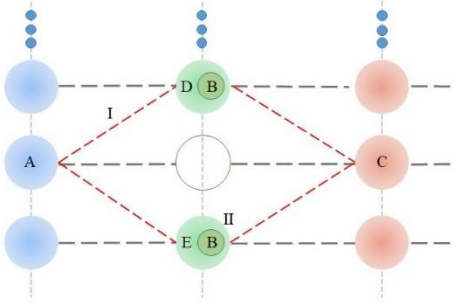
Connectivity has the strongest applicability among the three topological properties, which can connect any element apart from the previous connectivity in the four territories. Change on this plane is equivalent to any two points sticking together on the plane, not continuous transformation, belonging to the topological variant. On the contrary, the existing connectivities can also be disconnected, which is equivalent to tearing on the plane, also belongs to the topological variant. The greatest feature of connectivities between elements is the reverse deduction from the result. It can also be said that there is an idea that participants should try their best to realize. The possibility of establishing or changing connectivities is meaningless between elements drastically, which requires participants to identify these ideas and select those meaningful ones. It's much more efficient to quickly create ideas and then choose from them than to gradually deduce them from the current situation (e.g. Brainstorming and Concept Development). Brainstorming refers to a group of participants talking about their ideas. This process is actually to motivate and restrict each other by bringing together people's ideas. A participant can be inspired by the ideas of other participants and express his own ideas. This is a process of being motivated. At the same time, a participant cannot say what others have said, which is a restricted process. Brainstorming can end when all participants'ideas are nearly exhausted. Then it summarizes and evaluates the ideas generated, and finally makes a screening to select the best ideas. In TVC, new connectivity is generated directly between the elements in the four specified territories, and the efficiency of generating ideas is greatly improved.

5.3.2 Topological properties of the hole

The number of holes is the most prominent feature of topological perception. In TVC, holes means that a node in four domains is forced to disappear, which automatically connects the points around the original set. As shown in Table 23, the general relationship between A and C is A connecting B, and then connecting C from B. When B is converted into hole, the connection between A and C becomes A and D, then C is connected from D, or A and E, and C is connected from E. The biggest change in the relationship between A and C is from a general relationship to two general relationships. When B is not converted into a hole, A can also connect to C from D or E, and the two relationships are ADC and AEC, respectively. But these two connections are not routine connections compared with ABC. Although the two new relationships can also be implemented through connectivity, there are possibilities to make them undetectable. By making holes, these two connections will inevitably arise. However, there is a chance to choose which node to transform the hole, so holes and connectivities can be seen as creating new connections in two ways that complement each other.

The hole can also actively create inside/outside. As shown in Table 23, when B becomes a hole, there are two choices, one is the above, B is abandoned, and the new relationship is established through connectivity. Another option is to think about how to put B in other elements of the same territory to create new ideas. The hole can drive the emergence of two other topological variations.

Table 23 Holes

Before the hole appeared	After the hole appeared
	

5.3.3 Inside/Outside relationship

Compared with the first two topological properties, the inside/outside relationship has some limitations. This property is more appropriately applied to every node in the same territories. Each node is regarded as a set, so that one set can be placed in another one, thus generating two new relationships of sets. It is more difficult to do inside/outside between sets of nodes in different territories. This relationship is different from the one established by connectivity. The relationship established by connectivity belongs to the external connection relationship, which is to achieve the mutual influence of two things that have not been connected before. The inside/outside relationship is the transformation of the internal or external relationship between two things. One is to establish the subordinate relationship between two things that had no previous connection, and the other is to transform the two things of the previous subordinate relationship into external relations. The form and content of the subordinate relationship are totally different from those external relations of the same elements.

5.3.4 TVC

We can turn one type of problem into an equivalent problem and another type of problem into a purely mathematical problem. The equivalent problem is essentially an empirical question because its task is to indicate the nature of certain empirical facts, for us it is to indicate the nature of the psychodynamic facts. To equate the facts with mathematical concepts, which describe the logical structure of these empirical relationships. The perception domain of the newborn has not been developed at all so that the simplest concept of connectivity or the concept of "components" is not applied, but the “topology” of what we call the perception domain is gradually being carried out (Lewin, K., 2013).

One of the most important general attributes of psychological life space is that it is

not infinitely structured but always structured to some extent. Even if we use a fixed measuring scale, we must consider the nature of the physical process itself. Köhler's argument clearly shows that physics and psychobiology can use the same concept of "dynamic whole" or "gestalt", and the basic rules of Gestalt are also applicable to these two sciences (Levine, S., 2000). So far, we can basically understand Lewin's efforts in introducing topological research into psychological problems, as well as the basic ideas (Tucker, I et al., 2014). It also makes us really confident in using "topological method" as a very basic symbol system to describe psychological facts. The biggest difference between psychological space and physical space may come from the meaning attribute of psychological space, namely, all existing structures of psychological space are based on certain meaning, and the generation and change of meaning determine the composition of mental space. Before then, although objective things existed, they did not constitute a psychological living space.

TVC also takes the way of visualizing people's creative psychological activities, showing the content, thinking process and psychological structure changes that exist in the psychological space. The topological analysis of psychological life space makes the psychological process which belongs to the material world really differentiate and become an independent world that can be described directly. Moreover, the two worlds establish a clear structure of the material, psychological and value by means of value communication. From a topological point of view, a drop of water is completely equivalent to the earth. There is no difference between a cube and a sphere. However, these non-metric spaces exhibit important properties that are fundamental to metric spaces. The whole-component relationship and the interrelation of components play an important role in psychology. The concept of road plays an important role in the structure of psychological space. People can make certain psychological facts with the function of psychological connection between two psychological "points" equal to a "road" connecting two points mathematically. Of course, there is no measurement for mental life space at present. Obviously, the distance of physical space, generally

speaking, is not equivalent to the distance of psychological space. However, at present, the qualitative change of new product innovation can be distinguished by topological properties and variations.

We observe things visually and produce a series of psychological activities. The content generated by these psychological activities is then translated into knowledge. In the process of conversion, we choose a variety of ways and use a variety of methods. The generation of TVC also follows this process. From the visual cognition of novel products as the starting point of research, the principle of topological cognition is taken as the theoretical basis of the research, and it is found that topological variation can explain the phenomenon that people pay attention to novel things. Thus, the topological variation is visualized into a sheet, and the interaction between the product and the human is decomposed on the sheet. Through the topology mutation operation, novel product design ideas can be obtained. The importance of TVC lies in visualizing the implicit knowledge of creating and transforming it into explicit knowledge dissemination to students. In product design teaching, students' product design creativity can be enhanced.

Chapter 6

Discussion

Content

Chapter 6. Discussion

6.1 Findings and advantage

The starting point of this study is the theory of topological perception, which gives priority to the recognition of visual topological variations. Then the priority of visual topology perception is validated in product design. Experiments show that the priority of visual topology perception is valid in product shape recognition activities. Moreover, through the correlation between product design creativity and visual topology perception, it is found that product design creativity can be expressed by visual topological properties and variations, and The possibility of introducing high-quality, innovative products can be artificially created through visual topological variations. Topological psychology has also become the theoretical basis for this discovery. In topological psychology, the method used to determine the structure and attributes of the brain field is the same as the method used to determine the structure and attributes of the living space. This consistency is particularly evident in the fact that the problems of dynamic relations and location relations play a particularly important role. The inference of events proposed here only means traceability, i.e., from the phenomenal attributes of objects and events themselves to the condition-occurrence attributes. Topological psychology emphasizes subjectivity (Lewin, K., 2013). It studies the psychological positional relationship centering on the subject. Since the theoretical basis of this research comes from topological visual perception theory and topological psychology, this study has three distinct advantages.

6.1.1 Prescriptive operation

The visualized sheet serves as a tool to help students generate product design creativity. The visualized sheet serves as a tool to help students generate product design

creativity. In this sheet, as long as the topology variations are manipulated, the hole and inside/outside are created, and new connectivity is established, a new interaction can be generated between the product and the person, thereby creating a new experience. Whether these creativities can be realized and how they are implemented is the focus of the next stage. The important thing is that the idea has come. The characteristic of topological variations is generating ideas first, or by making assumptions first, and then demonstrating whether these creativities or assumptions can be achieved. Other design methods are to create various means to create creativities or assumptions. From this aspect, topological variation is prescriptive, reducing human mental work, or moving the human brain activity from generating ideas to demonstrating the feasibility of creativity, reducing the intensity of mental activity. The results from the experiment can be verified, and some subjects with poor product design creativity will have more obvious progress.

6.1.2 Less time-consuming operation

According to the time statistics in the experiment, the three design methods visualization, Analogy, SCAMPER are longer in generating the creative idea than the TVC.

Visualization firstly spends most of its time on presenting things, scenarios, and thoughts in an imaginary way on paper, and then discovering ideas with potential for development based on the images. If the picture doesn't provide useful ideas, start over. Such a process is bound to take a lot of time.

The time consumption of analogy is mainly in the process of thinking. The subject should find another thing that people are more familiar with as a carrier instead of designing the subject matter. Its main purpose is to effectively convey the most prominent features of the subject matter through the carrier, which is conducive to people's understanding.

SCAMPER takes the longest time because it has more content, both commanding features, divergent thinking, convergent thinking. Subjects try to design the subject matter and follow each instruction. It is obviously unrealistic to try each instruction under limited time, and in actual design activities, the time limit is normal.

The short time taken by TVC is mainly due to its mandatory features. The time required for creativity is critical to product design, product design has more commercial attributes, and time is part of the cost. And the intensity of mental work is also a hidden cost. At the same time, our thinking is mainly focused on divergent thinking, using our imagination, the process of our brain is much stronger than the logical thinking of achieving creativity.

6.1.3 Significant effect

The probability of creating high qualitative creativity in the early stage of product design. From the relatively basic level of knowledge science, creativity can be understood as discovering and establishing new connections in previously isolated things. We observe things visually and produce a series of psychological activities. The content generated by these psychological activities is then translated into knowledge. In the process of conversion, we choose a variety of ways and use a variety of methods. The generation of TVC also follows this process. From the visual cognition of novel products as the starting point of research, the principle of topological cognition is taken as the theoretical basis of the research, and it is found that topological variation can explain the phenomenon that people pay attention to novel things. Thus, the topological variation is visualized into a sheet, and the interaction between the product and the human is decomposed on the sheet. Through the topology mutation operation, novel product design ideas can be obtained. The importance of TVC lies in visualizing the implicit knowledge of creating and transforming it into explicit knowledge dissemination to students. In product design teaching, students' product design

creativity can be enhanced.

6.2 Contribution to KS and PDE

Product design is a highly systematic work. Most of the design pioneers are exploring the problems of form and function. Design is also regarded as an important means to solve the relationship between them. However, people have a very wide and complex understanding of the scope of design problem-solving and the scope of function and definition of design. The design has begun to be regarded as a means of solving functions, creating markets, influencing society and changing behavior, not only the problems of function and appearance (Brown, T., Wyatt, J., 2010). This extension of the domain also makes the design more and more complex. Great changes have taken place in modern design in the 1990s, especially in the field of product design.

6.2.1 Contribution to KS

Design is a plan to create new things. From the perspective of knowledge science (KS), the design creates new things as well as new knowledge. New knowledge can promote the development of design or other industries. Then the new knowledge is from the tacit knowledge as the starting point. After the scholar's own research, in the process of communication with other scholars in the academic circle, it is gradually confirmed and perfected, and finally forms a recognized research result, namely knowledge. Although the process of knowledge generation is so easy to describe, the transformation from tacit knowledge to explicit knowledge is highly valued by the academic community. Scholars are trying their best to promote tacit knowledge to transform explicit knowledge. In the process of design, especially the early ideas, many of the content can not be expressed in the language. In product design education, we can only rely on the communication between teachers and students, students' own understanding, and gradually understand the principles of creativity. From the perspective of

knowledge science, TVC reveals the roots and evolution of creativity as a visual sheet, revealing that the root of creativity is to create new connections between things. In a narrow sense, TVC is a visual plane that can be applied to product design creativity. In a broad sense, TVC is a key to open the door to the study of the cognitive laws of new things, as well as the study of many psychological concepts.

6.2.2 Contribution to PDE

The commercial operation of the 5G network indicates that human life has really entered the era of the interconnection of all things. The interconnection of all things not only realizes the interconnection of all kinds of things in our life, but also brings about the change of production and lifestyle because of this great progress, which leads to the active period of elimination and innovation of all kinds of products, which indicates that product design activities will be carried out in the future (Zawadzki, P et al., 2016). Enter an epoch-making development period in the history of design. Therefore, changes should be made in the field of product design education (PDE) to adapt to the new era. This is a rare opportunity to produce high-quality products design methods worldwide. We should not only master the core science and technology independently but also have advanced product design theory and methods to catalyze the application of core technology in products (Shrouf, F et al., 2014). Creating new product design theories and methods is very important basic research work in universities (Kusiak, A., 2018). Only by renewing the original theory and methods can we create new products from the fundamental level of design. We are combining core technology with advanced design to create products with core competence.

With the improvement of product intellectualization, many functions have been implemented in software programs, which leads to the disappearance of some parts of the product and makes the product form more concise, which is also a reason for the convergence of similar competitive products in form. Although products are in the

period of rapid technological innovation, people's cognitive activities of product form are still developing according to their laws (Plattner, H et al., 2010). The advancement of science and technology is very important, but people are always the subject. Designers can't pay attention to the development of science and technology and ignore human beings. The most fundamental and lasting feature is people's novelty hunting, and people will quickly notice new forms of things. It is the most critical task for new products to attract consumers' visual priority in competing products of the same kind. Only by attracting consumers' attention can non-visual content such as function and performance of products be further understood by consumers. Topological visual perception is the fundamental and primitive functions of human beings vision system. The product form design theory and method developed from this basic visual perception feature is minimally influenced by regional culture and ideology and has a strong universality. It is suitable for the rapid globalization of the commodity market and can attract the attention of consumers to the greatest extent.

6.3 Limitations

There are four territories of division, and the division of parts of each territory is still far–fetched in some products. In TVC is more suitable for daily products, transportation, and other products, focusing on product form, product function, user experience innovation. However, the applicability of thematic cultural creativity products is not strong. Cultural creativity products refer to taking culture as creative elements, combining regional characteristics and theoretical knowledge of disciplines, through innovative design, giving different carriers a new cultural appearance (Moalosi, R et al., 2010). Designers through the combination of culture and design products, so that design has the value of commodities themselves, but also increased the added value of culture so that traditional culture has been greatly promoted, which is also in line with the creative economic development model actively advocated by the present society (Naranjo Valencia, J. C et al., 2010). In the design of cultural creative products,

the cultural symbol is the core of the design of creative products. It is not simply the decoration of creative products, but the reference of local cultural characteristics, which is the difference between creative products and general products (Makkuni, R., 2013). We should fully understand the traditional culture to be used in the design. Only by fully understanding can we discover the unique feelings of consumers towards national culture, and can we make cultural creative products that directly hit the hearts of consumers. In the design, appropriate ways should be used to make consumers feel the connotation of cultural and creative products, and pay attention to the communication between people and products. Because cultural and creative products emphasize the expression of information such as culture and ideas contained in products, the shape of products is determined by the theme, and the functions of products are not emphasized more, often with some commonly used functions. At present, the status of TVC research shows that if cultural and creative products are forcibly nested among them, it is indeed far-fetched. Therefore, the form of TVC will be further enriched and improved.

TVC is currently focusing on the design of individual products, but the reality is that people face product systems rather than individual products. In other words, while studying the relationship between people and products, we must consider all the products involved in the specified range. In this case, the single visual sheet is obviously not suitable for the production system design. Future research efforts will focus on the application of topological variability in product system design.

Chapter 7

Summary and conclusions

Content

Chapter 7. Summary and conclusions

7.1 General conclusions

In the past, in the product improvement design, the design of new product form relies more on experience, that is, the design of the new form and existing products are compared, through the experience of designers to judge the degree of innovation of form. In the design education of design institutes, there are many design courses, which are designed to enable students to gradually master the design ability and have a certain degree of design literacy. The goal of design education is to cultivate design talents with the ability to continuously create new things and improve people's quality of life. For a novel product, people always unconsciously notice it. Notice that this activity is very short-lived, but it is significant because it is likely to become an important factor in consumers' decision to buy what kind of goods. Starting from the goal of human attention to product form innovation, the author tries to infer the root cause of this phenomenon. TVC has a relatively effective prescription. The innovative ideas generated by three kinds of topological variations can enable students to generate creative idea quickly, and the ability to generate creative idea has been greatly improved even for those students with weak design ability.

7.2 Significance and contribution of this research

The significance of this study is to link human cognitive activities, thinking patterns and mathematics. Human cognitive activities and thinking patterns have certain mathematical properties and can be studied from a mathematical point of view. There are many schools of research on human cognitive activities and thinking patterns, among which Gestalt Psychology, with experimental psychology as its main research mode, has made abundant achievements. The school advocates the study of direct experience and behavior, emphasizes the integrity of experience and behavior, holds

that the whole is not equal to and greater than the sum of parts, and advocates the study of psychological phenomena from the perspective of an overall dynamic structure. Gestalt psychology uses field theory of physics to explain these direct experiences and behaviors and hopes to use it to make a new interpretation of psychological phenomena and mechanisms. However, these findings are manifested in a variety of human activities, after all, they are still at the level of experience. TVC is based on topological invariances and variations. It is suggested that human cognitive activities and thinking patterns are related to changes in topology. This shows that we have found the basis of topology in our experience, and TVC has a greater degree of universality.

TVC is not only a method of product design, but also a way to reveal the process of the creative idea generation, and it has contributed to the knowledge science. Creativity is the process of product innovation design and seems to be very casual. Designers are often referred to as inspiration. Many designers pay special attention to the generation of inspiration. Inspiration is important for art and design, but the difference is the frequency and relevance of the demand for inspiration. The frequency of artists' demand for inspiration is not very strong, and the correlation between inspiration and inspiration is not strong. The requirement of inspiration in design is just opposite to art. Not only should inspiration appear frequently, but also the relationship between inspiration must be strong. Design is a creative activity, which emphasizes system characteristics and commerciality. New products should be planned and strategically put into the market for consumers to choose and buy. The creative methods provided by TVC are not significant in guidance and enlightenment but have strong execution. As long as three kinds of topological variations are selectively operated of TVC, it is possible to obtain new ideas. In the previous experiments, it can be seen that the quality of personal design has been greatly improved by ordinary students who have passed the operational design ability of TVC without notifying the purpose of the experiment. Therefore, the contribution of TVC is mainly to provide a relatively high level of innovative thinking that can be sustained.

The statement can be said that knowledge must meet three conditions. It must be verified, correct, and believed. To create knowledge, people transform tacit knowledge from the beginning into explicit knowledge. After repeated publication, they listen to the opinions of other people, and then revise, and finally form recognized knowledge. The so-called innovative thinking is to discover or establish new links between things that were not previously connected or to change the original links between things that were already connected and establish new links. Innovative ideas often break the existing logic, so the production process itself is not composed of established logic, and it is difficult to describe it in words. But from the perspective of topological variations, the creative ideas generated by TVC come from three topological perceptual properties: connectivity, caves, internal/external. It visualizes the process of creativity generation and makes the process of creativity generation very clear. There is a correlation between people's innovative thinking and topological variations. This discovery will continue to be validated in future research until it becomes recognized and correct knowledge.

7.3 Outlook

How to judge the quality of innovative thinking used to depend on people's subjective judgment. This is the same innovative idea. Some people think it is good, but others think it is nothing. Of course, there are many reasons for such a big contrast. Everyone's knowledge reserve, living environment, cultural background, ideology and so on are not the same. These differences will produce different judgment results for the same innovative idea. It is for so many reasons that innovative ideas should be evaluated relatively objectively. TVC is likely to provide a measurement method with objective attributes. To the extent of this study, holes and inside/outside produce fewer ideas than connectivities because we can connect the nodes representing two things freely. We can also apply the topological variations of holes and inside/outside to the nodes representing two things in the model, but there will be fewer feasible solutions. The creativity displayed is highly appreciated by people.

With the homogeneity of products becoming more and more serious, designers should consider the systematic design of products. While innovating design, they should focus on the overall design collocation and combination. At present, it is quite common in design. Nowadays, an industrial design can be said not only to enhance the function of products but also to improve products. The popularity, the appearance of the product or the prominence of a certain point in the structure, is also the focus of attention to attract consumers, so the current industrial design is also constantly systematizing and specializing. In the information society, human beings yearn for the harmonious coexistence of man-machine environment, which requires designers not only to consider the functional needs but also to consider the emotional language of products, whether they can achieve the purpose of emotional appeal (Nagai, Y., 2015). If consumers can find psychological resonance in products and have a pleasant attitude, this is the embodiment of an excellent product. At present, this development is also a possibility in the future.

Future research will apply the model to a wider range of creative activities, not limited to the product design process. Using the principle of the model, it can be extended to other event processing. In a word, when we adopt new methods to deal with problems, we often get new results, which will exist as reliable knowledge.

Supplementary Material

Department	Constructs
Wheels	General spokes——decorative spokes
	High-tech —— low-tech
	Complete empty wheel——incompletely empty wheel
	With design interior—— general interior
	Thin tire——thick tire
	Empty——nonempty
	Empty——nonempty
	Empty wheel——nonempty wheel
Frame	Traditional——novel
	Symmetric——asymmetric
	Standard order connection——Nonstandard order connection
	Dynamic sense connection——rigid connection
	Directional——non-directional
	Speed sense——stable
	Dynamic sense——stable
	Dynamic sense——stable
	Harmonious——contrast
	U construct——no U construct
	Dynamic sense——stable
	Powerful——delicate
	concise——Fussy
Seat	One point connection——two points connection
	Dynamic——stable
	Comfortable——uncomfortable
	concise——complex
	elastic——rigid
	elastic——rigid
Pedal & chain rings	Inside rim——outside rim
	Inside rim——outside rim
	Top of rim——bottom of rim
	Big hole——small hole
	Inside rim——outside rim
	Inside rim——outside rim
Whole	Normal riding——abnormal riding
	concise——complex
	stable——contrast
	Cool——Mediocre
	Harmonious——loose
	Tough——soft
	Few elements——Multielement
	Future——Contemporary

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The list of research achievements

International Journal Papers

1. Fei, F., & Nagai, Y. (2019). Topological perception on attention to product shape. *International Journal of Design Creativity and Innovation*, 1-14.

International Conference Proceedings

2. FEI Fei, Yukari Nagai, Impact of Visual Topological Features on Priority Attention for Product Shapes, International Association of Societies of Design Research(IASDR), specify the status of the paper: accepted, 11pages, November 3, 2017, University of Cincinnati.
3. FEI Fei, Yukari Nagai, Impact of Visual Topological Features on Priority Attention for Product Shapes, Research into Design for a Connected World, 2019 (ICoRD), specify the status of the paper: in the press, 10pages, January 9, 2019, Indian Institute of Science, Bangalore, India.

Domestic Conference Proceedings

4. FEI Fei, Yukari Nagai, Impact of Visual Topological Features on Priority Attention for Product Shapes, JAIST World Conference, 2018 (JWC), poster presentation, February 27, 2018, JAIST.

Awards

5. Excellent Poster Award. FEI Fei, Yukari Nagai, Impact of Visual Topological Features on Priority Attention for Product Shapes, JAIST World Conference, 2018 (JWC), poster presentation, February 27, 2018, JAIST.