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Creativity in Innovation Design: the roles of intuition, synthesis, and hypothesis*

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ABSTRACT

In a highly technologically-advanced mature society, a shift in focus occurs from quantitative to qualitative innovation. This paper discusses this shift from the perspective of design. We address these future topics by showing our views or opinions, as well as by referring to some theories and arguments that have appeared up to the present in this regard. Concretely, we postulate that the design process comprises the stages of intuition or gut feeling, followed by analysis or synthesis, finally leading to the design outcome. Assuming that one of the factors that determines design creativity is whether the purpose or goal of a design is inside or outside of the design process, we also examine the aspects of these conditions. We then suggest the idea of an Innovation Design process model composed of two cycles: analytical design creation and synthetic design creation. In the former, a design solution is explored to fulfill a purpose or goal pre-assigned to a product from outside, leading to quantitative innovation. In the latter, hypothesization starting with an intuition or gut feeling leads to the design of a breakthrough product, leading to qualitative innovation. Finally, we present an outline of the design school (workshop) conducted based on these thoughts.

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1. Introduction

Through products (in this paper, all outcomes of design, including industrial products, plants, and buildings, are referred to as 'products'), science and technology[1] have thus far protected human beings from unfortunate natural disasters and rendered our daily lives more convenient and abundant. Today, however, our relationship with science and technology has become more complicated, as evidenced by cases in which science and technology, while they continue to advance and bring about material fulfillment and machine-based civilization, also jeopardize humanity. For this reason, the question as to what products should be produced is likely to become more important in the future. As a way to seek an answer to this question, we discuss focusing on a shift from quantitative to qualitative innovation by showing our views or opinions on this shift from the perspective of design, as well as by referring to some theories and arguments that have appeared up to the present in this regard.

First of all, let us clarify the meaning of the term 'Innovation Design' that we use here. The word 'design' is in frequent use today: it is used in such terms as industrial design and mechanical design, as well as corporate design and career design. As for 'innovation,' in this paper we focus on changes brought about in society by science and technology and discuss them from the perspective of design. In this sense, we call the act of bridging science and technology and society[2] through products (Taura,

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* This article has been translated from the original Japanese article (Taura & Nagai, in press).

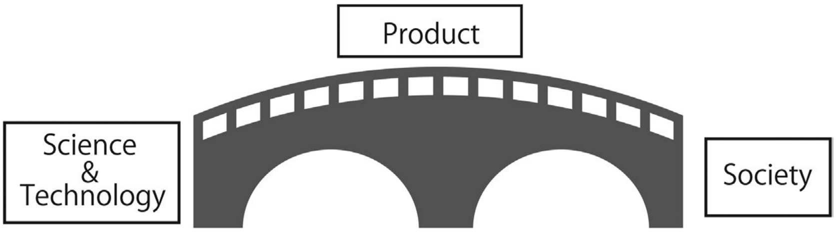


Figure 1. Innovation design.

2016) 'Innovation Design,' for which 'design' or 'designing,' the act of thinking up product structures and shapes, is carried out.

Present-day innovation design is confronted with the challenge of figuring out how to continue to design breakthrough products that society wants (in this paper, breakthrough products refer to products that demonstrate high levels of originality and practicality). Before examining this challenge, let us first ask where design should begin, in other words, where the starting point of design should be placed. The illustration of Innovation Design shown above (Figure 1) suggests the following three possibilities.

Firstly, design can begin with the recognition of societal changes. This involves listening carefully to product users' voices. This is 'needs-led' design. The introduction of a new product into society is often preceded by market surveys to study user needs and other marketing activities. This is only proper, considering that users make the final evaluation of the product and decide whether to buy it or not. A method for detecting latent needs has recently been proposed which involves a designer infiltrating an area or community in which a given product is likely to be used to 'empathize' with its members and thus identify their latent needs (http://dschool.stanford.edu/). The notion of 'user innovation' has also been proposed, meaning that users lead innovation (Faulkner & Runde, 2009).

Secondly, design can begin with discovery or development in science and technology. This is 'seeds-led' design. In fact, when basic knowledge is acquired about a new material, information technology and so forth, it is often the case that products are sought out to which the new knowledge can be applied. For example, in the case of carbon fiber, its structure and manufacturing methods were first developed, and the scope of its application has rapidly expanded, now including even aircraft fuselages. In general, the term 'innovation' is most often used in this sense (that is, technological innovation).

Thirdly, design can begin with the generation of a product idea aimed at bridging needs and seeds. This design process comprises, in the first place, the formulation of a new concept of product based on existing science and technology, followed by research and development in basic science and technology or assessment to evaluate the acceptability of the new product in society, as the necessity arises. As we will discuss below in Sections 2 and 3.5, some breakthrough products that have had great impact on society have been designed in this manner. This approach is not about ignoring seeds or needs, but about placing the starting point of design on product concept generation.

These three approaches are not mutually exclusive, but they can be applied in parallel. Both seeds and needs are essential for design. In actual cases of breakthrough design, the three approaches are often integrated. While recognizing this, we examine them separately in this paper because we believe it important and necessary to discuss what should be most emphasized at the beginning of the process of realizing a breakthrough product: fulfilling needs, utilizing seeds, or bridging the two. In the first approach, in which design begins with understanding needs, resultant products will probably be useful for society. However, this approach, located far away from the context of science and technology, is less likely to generate ideas for products that embody the latest science and technology. On the other hand, the second approach, in which design begins with research on, or development of, seeds, runs the risk of failing to produce products that meet user needs because this approach is located far away from the social context. For this reason, we will develop our argument here by making the third approach central.

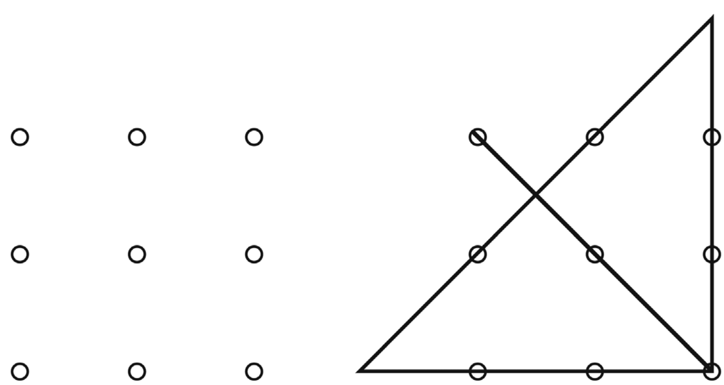
In the following sections, we will discuss types of creativity in Innovation Design (Section 2) and various aspects of creative thinking in Innovation Design (Section 3). Based on these discussions, we will propose an Innovation Design process model (Section 4). Finally, we will present an outline of a design school (workshop) that was conducted on the basis of the thoughts discussed in this paper (Section 5).

2. Types of creativity in Innovation Design

The generation of ideas for breakthrough products requires creativity. What kind of creativity is required, then, for Innovation Design? In this paper, we will further develop our previous discussion on design creativity (Taura & Nagai, 2012) from the perspective of Innovation Design. We believe that there are two major types of creativity.

The first type of creativity is the out-of-the-box creativity that generates ideas that depart from what is believed to be common sense (conventional, preconceived notions). This type of creativity is typically demonstrated in the solution of the famous nine-dot problem: Nine dots are arranged in the form of a square, and you must connect all of them with four straight lines without lifting your pen from the paper and without tracing the same line more than once, as shown below (Figure 2). The key to solving this problem is whether or not you realize that you are allowed to draw lines outside the square area. In other words, an essential part of this type of creativity lies in successful elimination of preconceived notions. This is a matter of fixation (we will take this up again under Section 3.2). In design research as well, fixation is an important subject that has drawn much attention. An experiment was conducted to study how design results are influenced when designers (experiment participants) are shown design examples beforehand (Jansson & Smith, 1991). This type of creativity is manifested in many actual breakthrough products. HondaJet[3] is a representative example (http://world.honda.com/HondaJet/).

The other type of creativity is demonstrated in a concept of breakthrough product resulting from the combination of several elemental pieces of knowledge or technology. Duggan points out that many important scientific discoveries and breakthrough products have been realized through the combination of several existing elements of knowledge or technology, citing such examples as the achievements of Copernicus and Newton, who selectively recombined several elements of existing knowledge into a new whole; the original Macintosh computer, a product of combining graphical



(a) (b)

Figure 2. Nine-dot problem: (a) problem; and (b) a solution example.

user interfaces (GUI), then under development at Xerox, with a small computer frame; and Bill Gates' Microsoft achievement, in which Gates put together four existing elements which he had not invented: the Altair, its 8080 chip, BASIC, and the PDP-8 (Duggan, 2013). Christensen defines innovation as connecting seemingly unrelated ideas, while Steve Jobs said, 'Creativity is just connecting things' (Dyer, Gregersen, & Christensen, 2011). We have been conducting a systematic study on how two weakly related concepts can be combined to generate creative ideas (Taura, 2016; Taura & Nagai, 2012). This type of creativity that derives from 'connecting things' is not entirely unrelated to the first type of creativity, which derives from elimination of certain fixations as stated above (in some cases, conventional ways of connecting things are preconceived notions). Nevertheless, in this paper we consider these two types of creativity to be clearly different. This is because we believe that the way of thinking that enables the combination of several elemental pieces of knowledge or technology is free association-oriented and dynamic (as explained in Section 3.2), while the type of creativity that is centered on elimination of fixation is mostly concerned with setting a static viewpoint.

Keeping in mind the difference between these two types of creativity, we approach creativity in Innovation Design in this paper.

3. Aspects of creative thinking in Innovation Design

In this section, we will first discuss the concepts of quantitative and qualitative innovation, and then various aspects of creative thinking along the axes of intuition or gut feeling, analysis or synthesis, design solution or hypothesis, and whether the purpose or goal of a product to be designed is inside or outside the design process.

3.1. Quantitative or qualitative innovation

For decades up to the present, consumers have demanded greater convenience, and society has responded by pursuing efficiency. Concretely, automobiles, electric appliances, computers, power generators, and other products have been provided at steadily lower prices. To do so, increasingly specific and reliable design knowledge has been sought out. Consequently, modularization, standardization, and automation have advanced. The results of these developments have been so remarkable that our lives today seem almost totally free of perceptible inconvenience. Let us call this type of innovation, which contributes to augmenting quantifiable efficiency 'quantitative innovation.'

However, efficiency-oriented technology brings society quantitative change, not qualitative change. Let us call the type of innovation that contributes to society's qualitative change 'qualitative innovation.' Qualitative innovation gives birth to products that realize new lifestyles or lead to the creation of new cultures. For example, portable music players have enabled people to enjoy listening to recorded music anywhere, even while traveling by train, unlike in the past when it was only possible through the use of sound systems in fixed locations. The popularization of portable music players has changed the way people enjoy music, as well as how they spend their time on trains. These changes have in turn had cultural impact, influencing the way music exists in society.

Some voice the view that negative effects of the materialistic society brought about by science and technology have been offset by culture, arts, and design in the narrow sense of the term (arrangement of colors and shapes). Nevertheless, science and technology have also given birth to new cultural and artistic expressions, as in the example of the portable music player. We discuss below the possibility of exploration of human sensibilities by science and technology.

Let us think of illuminated night views as an example. We find such light-ups beautiful, but they are not something that exists in the natural world. An artificially created beautiful night view touches us emotionally. The same can be said of the Japanese sword. For its clear, pure, and mysterious beauty, the Japanese sword is nowadays appreciated and traded as a work of art. Yet, it is a product manufactured with highly refined specialized techniques, including heating, hammer-forging, and hardening. How is it possible that an artificially manufactured object moves our hearts? It seems that the way we feel our hearts resonating with night illuminations and the Japanese sword differs from the emotion we experience when viewing splendid natural scenery or beautiful cherry blossoms in full bloom (Georgiev, Nagai, & Taura, 2013). If so, this means that science and technology has created a kind of emotion that we have never experienced before. In other words, sensibilities left unexplored have been awakened by science and technology. In fact, historically we know that the development of new science and technologies, such as bronze casting and building methods, has produced sculptures, religious edifices, and other products of new styles one after another, promoting arts and culture.

We can use the above discussion to explain why some new products are widely used. The pinch-in/pinch-out manipulations on the screen of a smartphone (using thumb and finger, moving them together or apart on the screen to modify screen display size) are not manipulations that humans perform in the natural world, but we can perform them quite naturally. We have only recently come to adopt these manipulations as a result of technological development. Doesn't this mean that the smartphone has not only realized convenience and operational efficiency but also broadened the scope of what feels natural for us, thus offering a new meaning to society?

The above discussion gives us a hint towards promoting qualitative innovation. That is, it suggests the necessity of designing products that broaden the scope of sensibilities and what feels natural for us by utilizing the latest science and technology.

3.2. Intuition or gut feeling

Intuition or gut feeling is said to play an important role in decision-making. Steve Jobs spoke of the importance of believing in one's intuition, saying, 'And most important, have the courage to follow your heart and intuition' (Jobs, 2005). The importance of intuition or gut feeling in sophisticated decision-making has been discussed by many authors (Duggan, 2013; Gigerenzer, 2008; Gladwell, 2006).

What, then, is intuition or gut feeling?

A dictionary definition (www.oxforddictionaries.com/definition/english/) describes 'intuition' as 'the ability to understand something instinctively, without the need for conscious reasoning,' and 'gut feeling' as 'a feeling or reaction based on an instinctive emotional response rather than considered thought.'

Numerous studies have been carried out on the phenomena of intuition (e.g., Sinclair, 2011). These studies discuss intuition in connection with such notions as holisticity, analytical process, unconscious thought, decision-making, tacit knowledge, problem solving, expertise, and experience.

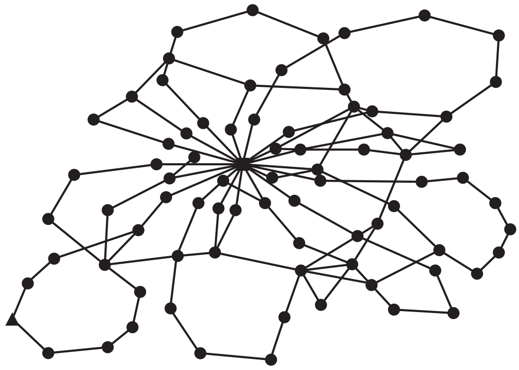
In the domain of design research, intuition or gut feeling has also been attracting attention. For example, a study collected characteristics of intuitive processes in design (Badke-Schaub & Eris, 2014), and intuition was discussed in connection with experientially formulated mental models such as schemata and scripts (Durling, 1999).

Duggan points to the utility of 'strategic intuition,' with which while pragmatically touching on existing elements, you organically combine them in a flash of insight for a new discovery, compared to 'expert intuition,' which is effective in solving similar problems faster and faster by recognizing their patterns as you get better at your job (Duggan, 2013).

Thus far, the terms 'intuition' and 'gut feeling' are not used strictly separately. In fact, the intuition mentioned by Jobs and Duggan seems to contain aspects that are closer to gut feeling.

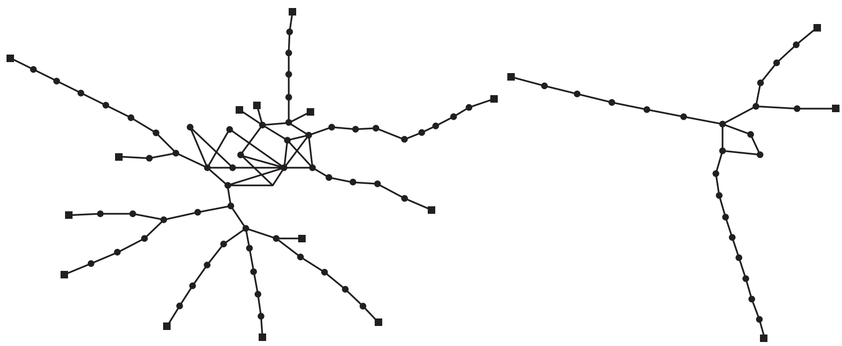
In view of the above, in this paper, we define 'intuition' as 'that which enables instantaneous decision-making following patterns recognized based on one's experience' and rename it 'experiential intuition,' and 'gut feeling' as 'feeling how something is or how something is related to another, based on one's sensibility' and rename it 'associative intuition.' Henceforth, the terms 'experiential intuition' and 'associative intuition' are used as thus defined.

Considering preconceived notions as one form of experiential knowledge, fixation, elimination of which is necessary for the first type of creativity discussed in Section 2, can be viewed as one manifestation of experiential intuition. In resolving the nine-dot problem presented above, elimination of



(a) (b)

Figure 3. Networks of associations in the process of idea generation: (a) process with more originality; and (b) process with less originality in the design outcome.



(a) (b)

Figure 4. Networks of association in the process of impression formation: (a) formed from a cup that a participant liked; and (b) formed from another cup that the same participant disliked.

fixation happens in a flash of insight. Thinking along this line, it can be said that experimental intuition itself can, in fact, hinder creativity in some cases.

The second type of creativity, on the other hand, can be viewed as creativity related to associative intuition, which can also be understood from the perspective of free association, as illustrated below.

We conducted a computer simulation of the process of generating new ideas by combining two weakly related concepts.[4] The simulation results revealed that the design outcomes with more originality (that is, the two weakly related concepts were successfully combined) involved more intricately intertwined and expanded associations than did those with less originality (Taura et al., 2012) (Figure 3).

Using a similar method, we conducted another simulation[5] of the process of forming impressions from various stimuli. We obtained results indicating that forming impressions from stimuli that a participant liked involved far more intricately intertwined and expanded associations than from those formed from stimuli that the same participant did not like (Taura, Yamamoto, Fasiha, & Nagai, 2011) (Figure 4).

These results indicate that the process of forming good impressions and the process of coming up with good ideas by combining weakly related concepts are based on an essentially identical mechanism. It is believed that this mechanism is related to the dynamic nature of associations that expand while they are intricately intertwined, and not to the static nature of associations centering around particular concepts such as 'star' and 'rose.' That is, pleasant sensations that we feel, such as the states of heart resonating to beautiful music or heart dancing due to creating something, are not mere reactions to particular seeds (stimuli), but they are resonances to the expansion and complexity of (free) associations, and the mechanism acting as a tuning fork-like resonator for this is assumed to exist in our heart.

From the above, we believe that the tuning fork-like mechanism of resonance mentioned above is at the source of associative intuition. This may be the 'gut' of 'gut feeling' or the 'heart and intuition' in the words of Jobs. We also believe that when an idea is connected with another (as in free association) in the way the tuning fork resonates, the connection manifests itself in a flash of insight.

As a summary of this section, we can say that a flash of insight in experiential intuition is the leap that accompanies elimination of fixation, and a flash of insight in associative intuition, the leap that is achieved when things are connected via sensibility (or resonance to sensibility).

3.3. Analysis or synthesis

Design process is said to be composed of analysis and synthesis. 'To analyze' is to understand the nature of something that already exists by breaking it down into several parts or constituent characteristics. 'To synthesize' is to combine various things that already exist into something that does not yet exist. For example, decomposing a physical substance increasingly minutely into molecules, atoms, and particles to investigate its properties is analysis. On the other hand, constructing a new machine with various components is synthesis. It is said that, while synthesis requires analysis, merely knowing how to analyze is insufficient to synthesize. Why?

One reason is found in the relationship between the whole and its parts. In holism (www.oxforddictionaries.com/definition/english/holism), the whole is regarded as greater than the sum of its parts. In other words, the whole cannot be reproduced simply by putting its decomposed components back together. What does this mean? In mechanical design, for example, an assembly is complete when the components are put together. Isn't this assembly then a 'whole'? This question can be answered with the notion of 'emergence,' which is advocated by Polanyi (1983). He wrote, 'The upper [level of reality] relies for its operation on the laws governing the elements of the lower one in themselves, but these operations of it are not explicable by the laws of the lower level.' He explained this with the examples of four levels: a town, houses, bricks, and raw materials. This means that workings at the upper level differ from those at the lower level, as in the way, for example, while an automobile's performance may come down to the performance of its engine and other components, merely getting an engine designer, a tire designer, and so on and so forth to work does not necessarily result in a good automobile design.

The difference between analysis and synthesis can also be explained by the difference in the knowledge structures (Yoshikawa & Taura, 1997). Knowledge obtained from analysis represents an orderly structure from which categorical ambiguities are strictly excluded. For example, an analysis of automobile engine performance involves obtaining quantitative data, which can be placed and compared on real number lines and expressed as a knowledge structure decomposed into direct sums (Figure 5(a)). Knowledge required for synthesis is not like this. As demonstrated by smartphones featuring functions allowing photo-taking, recording and playback, and other functions, a new concept is often generated when several existing elements are combined. The knowledge structure for synthesis must have overlaps (Figure 5(b)). These overlaps never result solely from analysis, however thoroughly it may be conducted. Overlaps are formed when elements of knowledge obtained from analysis (entities and their properties, expressed as elements and subsets) are rearranged and restructured so as to produce overlaps.

Let us put the above discussion in relation with our discussion in Section 2. Analysis requires a prefixed viewpoint. It should be noted, however, that analysis may not be adequately performed if an old viewpoint (of preconceived notions) is maintained. This means that analysis is related to the first type of creativity, while the second type of creativity is synthesis itself.

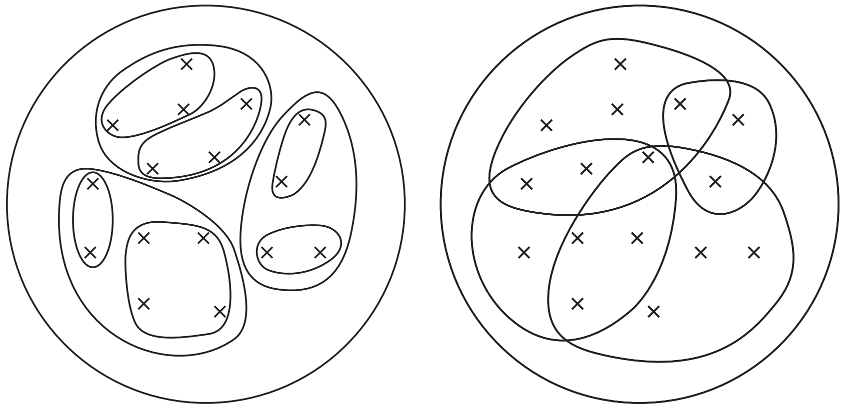


Figure 5. Different knowledge structures: (a) analysis; and (b) synthesis.
Notes: Figure 5 illustrates knowledge structures using set theory. The elements are actual objects such as products, and the categories (subsets) are their properties.

3.4. Design solution or hypothesis

Various expressions are used to refer to design outcome. In engineering design, it is often called 'design solution.' This is probably because engineering design is in most cases understood as problem solving, that is, finding a solution to a given problem. Meanwhile, mechanical, architectural or artistic design outcome can be perceived as 'hypothesis' (Yoshikawa, 1997) because design outcome is believed to derive from abduction, and not from deduction. Here is an overview of the difference between abduction and deduction.

Deduction is the reasoning that derives specific knowledge from general or universal knowledge. Syllogism is a typical example of deduction. Yonemori (1992) stated that deduction only involves taking up an already stated fact as the premise and restating it in conclusion, illustrating this with the example of obtaining the solutions $x = 5$ and $y = -4$ of the equations $x + y = 1$ and $2x + y = 6$. The intention of this example becomes clear when the equations are graphically expressed. The solutions of two equations are also the coordinates of the point at which two straight lines cross. Once the two lines are drawn on a graph, their cross-point is determined automatically which has always been implicitly contained in the two equations. Solving equations can be likened to making explicit the cross-point that is implicitly contained in the equations.

Abduction, on the other hand, is the reasoning by which we discover hypotheses.

In abduction, something is reasoned that differs from what is directly observed. Let us contemplate what 'hypotheses' are in this context. Based on the arguments of Peirce and Poincaré (Poincaré, 1902; Yonemori, 1992), the term 'hypothesis' can be classified as follows:

- Firstly, a hypothesis can be a 'cause'; for example, a physician diagnosing a patient's disease or a detective identifying a suspect is hypothesizing.
- Secondly, a hypothesis can be an 'explanation', such as a law of nature.
- Thirdly, a hypothesis can be a 'temporary fix'; it is also called a working hypothesis, such as an auxiliary line, including a medium line used in geometry to prove that the two angles of an isosceles triangle are the same.

Note that a hypothesis of a cause can be obtained deductively by collecting a large number of examples. Similarly, in some cases, a hypothesis as an explanation can be obtained inductively based on phenomena. However, the likes of the laws of Newtonian mechanics and auxiliary lines cannot be obtained deductively. In this sense, they can be considered as 'authentic' hypotheses. If prerequisites for a design can be reproduced in a laboratory or a desired design outcome can be achieved by improving on an existing product, design can be performed deductively by analyzing the problem. Meanwhile, designing a product that has never existed before requires the creation of a 'authentic' hypothesis.

In view of the above, different expressions for design outcome can be understood as resulting from the difference in the way design process is perceived, whether it is deductive or abductive.

Meanwhile, the term 'design solution' premises that a certain design outcome already exists (for example, an existing product) and implies focus on optimizing the performance, cost or some other attributes of the existing design outcome, whereas the term 'hypothesis' implies focus on adopting a temporary fix with the intention of ultimately discovering a novel product, although its possibility of existing is yet to be confirmed. As implied in a phrase like 'solving the problem correctly,' the validity of a solution is often attributed to the correctness of the procedure used to arrive at the solution (for example, correct calculation of material strength). The validity of a hypothesis, on the other hand, cannot be determined solely based on procedural correctness, and other data are usually required (for example, user evaluation of the product).

To sum up the above, the different expressions, 'design solution' and 'hypothesis,' point to the difference in notions of design, whether it is viewed as the act of solving a given problem, for which the pursuit of optimality through procedural correctness is required, or it is viewed as the act of finding a temporary fix with no guarantee of its correctness, from which the discovery of an unknown novel product is expected.

In connection with our discussion in Section 2, the nine-dot problem, presented to illustrate the first type of creativity, requires a solution, while a concept generated with the second type of creativity should be an (authentic) hypothesis. Along this line of thought, we can say that 'design solution' is related to the first type of creativity, and 'hypothesis,' the second type.

3.5. Product purpose/goal: outside or inside the design process?

There are two major styles of Innovation Design. In one of them, the purpose or goal of a product to be designed is given in advance, for example as in the case in which a product design is commissioned by a party that also provides product specifications. In some such cases, product specifications are determined based on user needs. In the second style of Innovation Design, the purpose or goal (specifications) of a product becomes clear as its design process progresses. Many systematic design methodologies belong to the first style (e.g., Pahl & Beitz, 1995). However, many of the actual design processes known to have produced breakthrough products are of the second style (Duggan, 2013). For example, in the cases of Gates and Jobs mentioned in Section 2, several elemental pieces of knowledge or technology were combined, but not to realize their desired product that would satisfy a pre-defined purpose or goal. It was the combination of elemental pieces of knowledge or technology that led them to find their product purpose and goal (specifications). We will further discuss this in Section 4.

The two styles of Innovation Design are different in that the act of determining the product purpose or goal is found either outside or inside the design process. From the perspective of systems theory, this can be paraphrased as whether or not design constitutes a self-referential system.

Let us now look back on the discussion in Section 2. In most cases, the first type of creativity is mobilized when the purpose or goal of the solution is given from outside, in the way the nine-dot problem is presented. On the other hand, the second type of creativity is usually at work when it is impossible to know exactly what functions (purpose or goal) the product-to-be will have until elemental pieces of knowledge or technology are actually combined. A predetermined purpose or goal can set restrictions on designing, and it is difficult to freely try various combinations while respecting the restrictions. Therefore, in many cases in which the second type of creativity is involved, the product purpose or goal becomes clear only as the design process progresses.

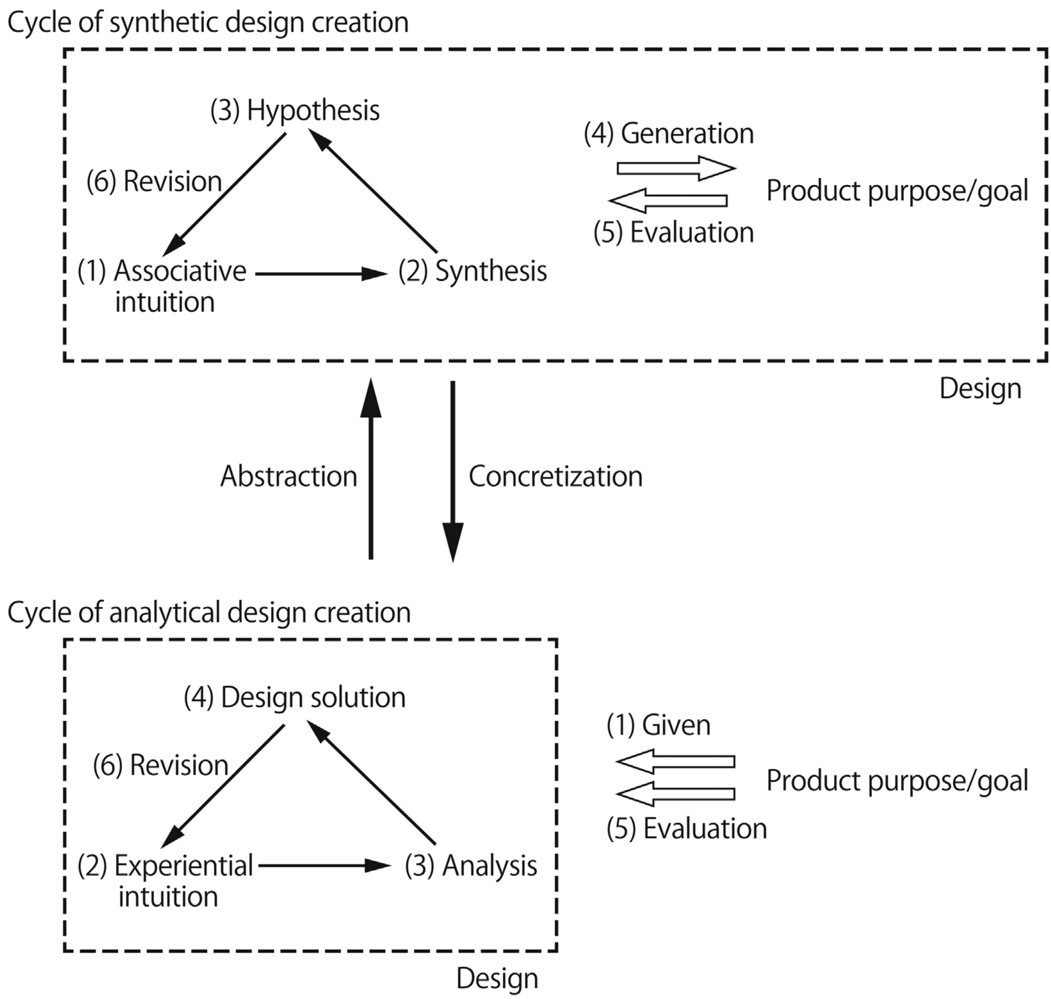


Figure 6. Innovation design process model.

4. Innovation Design process model

Based on the above, a process model of Innovation Design comprising two cycles can be drawn up (Figure 6; the numbers are the same in the figure and the text).

In one of the cycles, (1) a product purpose/goal is given from outside design, based on which a product concept (provisional design solution) is generated through the process of (2) experiential intuition, (3) analysis, and (4) finding design solution, in this order. The product concept is then subjected to (5) evaluation to check that it satisfies the purpose or goal, and (6) revision is performed,[6] if necessary, to finally arrive at the optimal concept (design solution). In the other cycle, design begins with (1) associative intuition,[7] followed by (2) synthesis and (3) discovering hypothesis. Then, (4) a product purpose/goal is found, and from this perspective the product concept (provisional hypothesis) is subjected to (5) evaluation, and (6) revision is performed as the necessity arises. Finally, an unknown concept (hypothesis) is discovered. In this paper, we call the former 'cycle of analytical design creation,' and the latter, 'cycle of synthetic design creation'; the creativity that is related to analytical design creation 'analytical design creativity,' and the creativity related to synthetic design creation, 'synthetic design creativity.' The two cycles respectively correspond to the types of 'analytical concept generation' and 'synthetic concept generation' discussed in the previous work (Taura, 2016), and 'problem-driven phase' and 'inner sense-driven phase' discussed in our previous work (Taura & Nagai, 2012). The term 'associative intuition' used in this paper covers the concepts of 'inner motive' in (Taura, 2016) and 'inner sense' in (Taura & Nagai, 2012).

In the cycle of analytical design creation, an existing problem is analyzed from a viewpoint intuitively (experientially) fixed in consideration of the (product) purpose or goal assigned in advance from outside to arrive at an optimal design solution. This is a problem-solving-oriented design flow (Pahl & Beitz, 1995). The problem-solving-oriented design that pursues optimality is effective in improving product performance, reducing cost, and achieving other quantifiable results. It is therefore considered conducive to quantitative innovation. Because of its contents (experiential intuition, analysis, design solution), the cycle of analytical design creation can be linked with the first type of creativity presented in Section 2. In this cycle, elimination of preconceived notions triggers a flash of insight, which leads to breakthrough product ideas. As an example of a product realized in a cycle of analytical design creation, HondaJet as mentioned above can be cited again. In the HondaJet project, Michimasa Fujino, in charge of development, pondered deeply, hoping to achieve the goal of securing a larger interior space in aircraft. He had a flash of insight and came up with the novel idea of placing the engines over the wings. After repeated rigorous analyses through simulation, the optimal shape (design solution) was obtained.

In the cycle of synthetic design creation, on the other hand, design begins with the designer's associative intuition, which connects (synthesizes) several elemental pieces of knowledge or technology to form a hypothesis. Conversely, a hypothesis is formed by synthesis that derives from associative intuition. This corresponds to Duggan's phrase, 'achievement, then theory' (Duggan, 2013). The purpose or goal of the product becomes clear as elemental pieces of knowledge or technology are connected. Because of its contents (associative intuition, synthesis, hypothesis), the cycle of synthetic design creation can be linked with the second type of creativity. In this cycle, the 'tuning fork-like resonator' at the source of associative intuition broadens human sensibilities, leading to qualitative innovation. Many breakthrough products resulting in qualitative innovation have been designed in the process similar or identical to the cycle of synthetic design creation involving the integration of multiple elemental pieces of knowledge or technology. It is said that the organizations that have achieved such product development obtained not only new products but also a new organizational vision, purpose or goal to pursue (Duggan, 2013).

Other than the obvious differences in elements between the two cycles (experiential/associative intuition, analysis/synthesis, and design solution/hypothesis), the differences between them are illustrated in Figure 6.

Firstly, the difference with regard to whether the act of determining the product purpose/goal is outside or inside design is indicated by the directions of the arrows from 'product purpose/goal' and the range of 'design' (dotted squares).

Secondly, the difference in terms of the starting point of design (design begins with the product purpose/goal given from outside in the cycle of analytical design creation, or with the designer's associative intuition in the cycle of synthetic design creation) is expressed by numbers assigned in the order of steps.

We have compared the two cycles so as to emphasize their respective characteristics to facilitate understanding about creativity in Innovation Design. However, the two cycles can be mixed in actual design processes. For example, immediately after a product purpose or goal is given from outside, the designer's associative intuition can trigger synthesis. In other cases, various analysis methods can be intuitively combined.

Moreover, transition can occur between the two cycles in either direction. In fact, a cycle of synthetic design creation rarely begins completely on its own. In many cases, it begins because an associative intuition emerges while the cycle of analytical design creation is repeated, leading to a new hypothesis (unknown concept). The same can be said about the cases of Gates and Jobs mentioned in Section 2. Initially, theirs were ordinary PC development projects. Serendipity, accidental discovery in science (Roberts, 1989), can be explained as a transition from one cycle to the other. The development of

Post-it® Notes by 3M, known as a typical example of serendipity, can be explained as such a transition. While trying to develop a strong adhesive (cycle of analytical design creation), a 3M researcher ended up developing an extremely weak adhesive; another 3M researcher later had the idea of combining the weak adhesive with bookmarkers (transition to the cycle of synthetic design creation), and Post-it® Notes came into being. In this paper, we call such a transition from the cycle of analytical design creation to the cycle of synthetic design creation 'abstraction' of design creation cycles.

On the other hand, when an associative intuition generates a product idea, and consequently the purpose or goal of the product is found, these phases are sometimes followed by the sophistication of product structure, shape, or other attributes, so as to improve product performance or usability to satisfy the purpose/goal. This means that the design process has transitioned to the cycle of analytical design creation. In this paper, we call such a transition from the cycle of synthetic design creation to the cycle of analytical design creation 'concretization' of design creation cycles. Concretization is indispensable for the commercialization of a product.

There are also cases in which a design process conducted in a cycle of synthetic design creation is later described within the framework of a cycle of analytical design creation, as an afterthought. This is because an analytical explanation generally reinforces persuasiveness. It is in fact a matter of perception: a product presented as a result of experiential intuition, and not associative intuition or sensibilities, sounds more convincing, just as a solution analytically arrived at to satisfy a predetermined purpose/goal, and not a purpose/goal finalized after aimlessly repeated trial and error, sounds more reliable.

5. Design school to enhance design creativity

This section presents an outline of the design school (workshop) that we conducted with focus on the enhancement of participants' synthetic design creativity (Yamada et al., 2017).

5.1. Basic policy of our design education

Synthetic design creativity is an essential driver for Innovation Design with the great potential of realizing breakthrough products. However, it has rarely been taught in a systematic way, except for some episodic mention, because synthetic design creativity is perceived as subjective, sensuous or lacking in persuasiveness, as discussed above. Nevertheless, we believe that expectation for synthetic design creativity will greatly increase in the future.

Therefore, we have constructed an educational method in which students can learn to generate breakthrough concepts and design products through group work by following a workflow starting with a cycle of synthetic design creation and then shifting to a cycle of analytical design. We then applied this method to a school (workshop) for students. Our basic policy, ideas and principles behind the educational method and the school, is described below.

In our educational method, concept generation begins with associative intuition. In general, academic instruction is required to be rationally founded. Design methodologies are often taught through practical training and exercises supervised by experienced designers. The rationale for these educational practices is experience. Associative intuition has been largely excluded from educational programs because it is considered irrational, often considered mere guesswork or random ideas popping up in one's mind for no reason. Yet, as we have discussed thus far, associative intuition plays an important role in actual design processes. Then, how should it be taught in educational programs? We believe that associative intuition itself is not something that can be taught. Nevertheless, we believe that, if associative intuition operates on a mechanism similar to that of the 'tuning fork' described in Section 3.2, it should be possible to lead students to polish their inner 'tuning fork' when it has become rusty, or to be more attentive to its resonances, even if not to create a new tuning fork.

Accordingly, in our educational method, students are taught to combine, through associative intuition, two seemingly unrelated elements (a living thing and a product) to generate new concepts, obtaining clues from metaphorical representations of living things, such as 'a bicycle like a dolphin'

(Taura, 2016; Taura & Nagai, 2012). This method resembles the method advocated by Christensen for enhancing the designer's ability to innovate, that is, involving idea generation based on a somewhat forced combination of weakly related concepts (Dyer et al., 2011). What distinguishes our method from Christensen's is that combination relies on associative intuition. Living things are used for their numerous excellent characteristics and their relative familiarity, which makes it easy to generate many ideas and associations. For these reasons, in the field of design as well, active research has recently been carried out in terms of biomimetics and biologically-inspired design (Goel, McAdams, & Stone, 2014). Because of its analogical structure, this type of metaphor is often used for problem solving. In our method, it is put within the framework of a cycle of synthetic design creation because metaphorical representations are made by associative intuition and product purposes and goals are gradually found as the design process progresses. By personally undergoing the process in which ideas are combined by associative intuition, concretized, and developed into breakthrough products that also suit their preferences, students are expected to become aware of the possibility and significance of discovering hypotheses through associative intuition.

The method also includes having students concretize the ideas they generate. This is because it is necessary in actual design to elaborate a design concept in the minutest possible detail to bring it to a feasible level and students are required to acquire skills for this task. Therefore, in our method, once basic ideas become well developed, students shift to a cycle of analytical design creation to examine concrete product structures, mechanism, and so on and produce 3D models.

Breakthrough products are expected to bring about new lifestyles, leading to qualitative innovation, as stated in Section 3.1. However, products to be designed do not exist yet. The new lifestyles that they are supposed to realize do not exist either and can only be imagined. This means that it would greatly assist both designers and users in their preliminary evaluation of future products in terms of novelty, utility, and so on, if they could virtually use the new products and observe how they change daily scenes, leading to new lifestyles.

In view of the above, our educational method includes the use of a virtual reality (VR) device, which enables students to view the projected images of designed products and their use in virtual reality simultaneously. The VR device used in the school was a variant of CAVE (Cave Automatic Virtual Environment), π-CAVE, the immersive 3D visualization system installed at the Integrated Research Center of Kobe University (http://www.eccse.kobe-u.ac.jp/pi-cave/). π-CAVE is composed of six screens (two in front, two on the floor, and one on each side) forming a rectangular cuboid 3 m high, 3 m deep, and 7.8 m wide, with a maximum capacity of 20 persons for simultaneous VR experience.

To summarize the above, the design procedure in our educational method proceeds in the following phrases: combination of a living thing and a product through associative intuition → synthesis → (transition) → analysis → CAD production of a 3D model → (evaluation: market survey, etc.). That is, students begin in a cycle of synthetic design creation and then shift to a cycle of analytical design creation. This flow differs from that generally practiced in design schools (e.g., http://dschool.stanford.edu/). Due to the limited time available, the procedure did not include product evaluation.

5.2. Design procedure

In the school, we conducted groupwork following the steps as indicated in Table 1.

5.3. Outline and results of the school

The school was conducted for four days from Thursday, 19 May through Sunday, 22 May 2016, at the Integrated Research Center of Kobe University, located on Port Island, Kobe City.

5.3.1. Participants

Eight students each from Kobe University (Japan) and Carnegie Mellon University (U.S.A.), all majoring in engineering (19–33 years of age; 12 males and 4 females) participated in the school. For

Table 1. Design procedure.

Step 1	Each team member lists 10 living things and 10 products
Step 2	Each team member chooses three living things and three products that he or she finds interesting from the lists made in Step 1, writes them down separately on Post-it notes, and affixes them on his or her team's sheet
Step 3	Each team member *intuitively* makes an interesting pair of a living thing and a product combined in the form of 'a [product] like a [living thing]' by choosing them from his or her team's lists made in Step 2
Step 4	Each team *intuitively* chooses one pair that its members find most interesting from among the pairs (four pairs per team) made in Step 3
Step 5	Each team member lists characteristics of the living thing of the team's pair chosen in Step 4, writes them down separately on Post-it notes, and affixes them on the team's sheet
Step 6	Each team discusses what shape, mechanism, service system, etc. that 'a [product] like a [living thing]' will have so as to represent the characteristics listed in Step 5, puts together ideas, and draws a sketch of the product. Each team imagines scenes in which the product will be used and collects visual images
Step 7	[Interim presentation] Each team presents its work done so far, using PowerPoint
Step 8	After receiving instruction in the use of the VR device, each team practices operation of π-CAVE with the projection of 360-degree panoramic images of scenes in which the product will be used. Each team examines how the product will be used in the projected scenes, as well as its size, structure, etc.
Step 9	Each team finalizes concrete details about its product such as structure and size, and creates a CAD model, following calculations if necessary. Each team collects more visual images of scenes in which the product will be used
Step 10	The instructors and staff carry out an interim review. Each team summarizes their design plan that has been discussed in the groupwork, explaining what has been achieved thus far and in what direction their work will proceed, and receives advice
Step 11	Each team continues designing concrete details. As the necessity arises, each team uses the VR device to examine how the product will be used, as well as its size, structure, etc.
Step 12	[Final presentation] Each team prepares a PowerPoint presentation and gives a demonstration of the product and scenes of its use using the VR device

Table 2. Results from step 2.

	Product	Living thing
R	Computer, Jet engine, Glasses, Watch, Purse, Robot, Car, Chair, Clock, Camera, Segway, Helicopter	Cockroach, Cactus, Lily, Kangaroo, Crane, Butterfly, Ant, Green caterpillar, Lion, Bacteriophage, Water strider, Elephant
G	Wheelchair, Vending machine, Motorcycle, Bicycle, Suitcase, Mobile phone, Glasses, Scissors, Watch, Scuba diving, Robotic pipeline inspector, UAV surveillance	Snake, Fly, Jellyfish, Bee Octopus, Bald eagle, Giraffe, Butterfly, Shell, Rabbit, Squid, Crab
B	Desk Organizer, Cup holder, Pen case, Lamp, Clock, Case, Scissors, Sunglass, Chopsticks, Glasses, Traffic light, Scooter	Llama, Turtle, Monkey, Giraffe, Peacock, Elephant, Tuna, Camel, Jellyfish, Shark, Monkey, Turtle
Y	Plane, Train, Hotel, Boat, Hot-air balloon, Sport car, Back-pack, Luggage, Bike, Bag, Fishing-net, Shoes	Starfish, Bird, Giraffe, Butterfly, Ginkgo, Water dog, Baleen whale, Armadillo, Octopus/Squid, Hummingbird, Gorilla, Mantis shrimp

instruction and school management, nine academic and administrative faculty members also participated. Four teams were formed, each comprising four members. They were named Team R(Red), Team G(Green), Team B(Blue), and Team Y(Yellow).

5.3.2. Design outcomes

Tables 2–5 indicate the results from steps 2–5 of the school. The final results (design outcomes), as shown in Table 6 and Figure 7, are not improved versions of existing products but are hitherto non-existent or highly breakthrough products.

5.3.3. Questionnaire survey results

Figure 8 indicates the results of the questionnaire survey conducted among the students who participated in the school.

The questionnaire survey results indicate that the participants evaluated the school favorably in general. Some of them also provided the following feedback: 'The design process was interesting and

Table 3. Results from step 3.

	Pairs
R	Camera–Ant, Chair–Cactus, Chair–Crane, Robot–Butterfly
G	Wheel chair–Squid, Suit case–Shell, Watch–Bee, Vending machine–Octopus
B	Desk organizer–Camel, Lamp–Monkey, Scissors–Shark, Traffic light–Turtle
Y	Sport car–Bird, Shoes–Bird, Plane–Hummingbird, Fishing-net–Baleen whale

Table 4. Results from step 4.

	Pair
R	Camera–Ant
G	Watch–Bee
B	Lamp–Monkey
Y	Fishing-net–Baleen whale

Table 5. Results from step 5.

	Characteristics of the living thing
R	Small, Robust, Strong, Eats, Underground, Makes a nest, Hard shell, Fangs, Communication, Modular, Acts as a swarm, Crawl, 6 legs, Cooperative, Hierarchy, Antenna
G	6 legs, Buzzing sound, Sense of direction, Large eyes, Co-ordination, Communication, Sting, Small size, Dance
B	Agile, Small size, Grabbing, Lightweight, Holding on with multiple means (hands, legs, tail), Stealing, Swinging, Long tail, Hanging
Y	Sucks in water + fish; pushes water out through its filter-like teeth; trapping the fish inside. → presses tongue against roof of mouth to push water out, streamlined, submersible, immune to cold, strainer, mobile, communication (hunting in groups), deep-diving, huge, cute, mysterious, gluttonous, black and white, hunter, fast?, large, does not echo-locate, uses air to shoal fish, can catch fish with sensor, expands/contracts in size, easy to catch fish, can catch small fish

Table 6. Concepts of design outcome.

	Product–Living thing	Product concept	Scenes of use
R	Camera–Ant	Ant-like small cameras that crawl into places which are difficult for humans to access, such as disaster sites, forming a swarm and each taking photographs	Disaster sites
G	Watch–Bee	A watch that transmits information (time, location, danger warnings, etc.) by bone conduction, like a bee that communicates its location or other information with its buzzing sound	Crowded places, inside an automobile
B	Lamp–Monkey	A lamp that can be fixed in various ways, similarly to how a monkey secures itself by holding onto objects using its hands, legs or tail, flexibly adjusting to the situation	Indoors
Y	Fish net–Baleen whale	A submarine that functions like a whale (blowing a bubble ring to trap fish in it, and emitting noise to confuse the fish) coordinates with other units to drive fish into a fishing net	Submarine, underwater

I learned some things I probably would not have without this inter-university collaboration.'; 'The design process to integrate two unrelated objects is stimulating.'

6. Human resources for innovation (in place of a conclusion)

Ideas for breakthrough products are often conceived by excellent leaders of distinguished quality, as examplified by HondaJet by Michimasa Fujino and many Apple products by Jobs. To be an outstanding

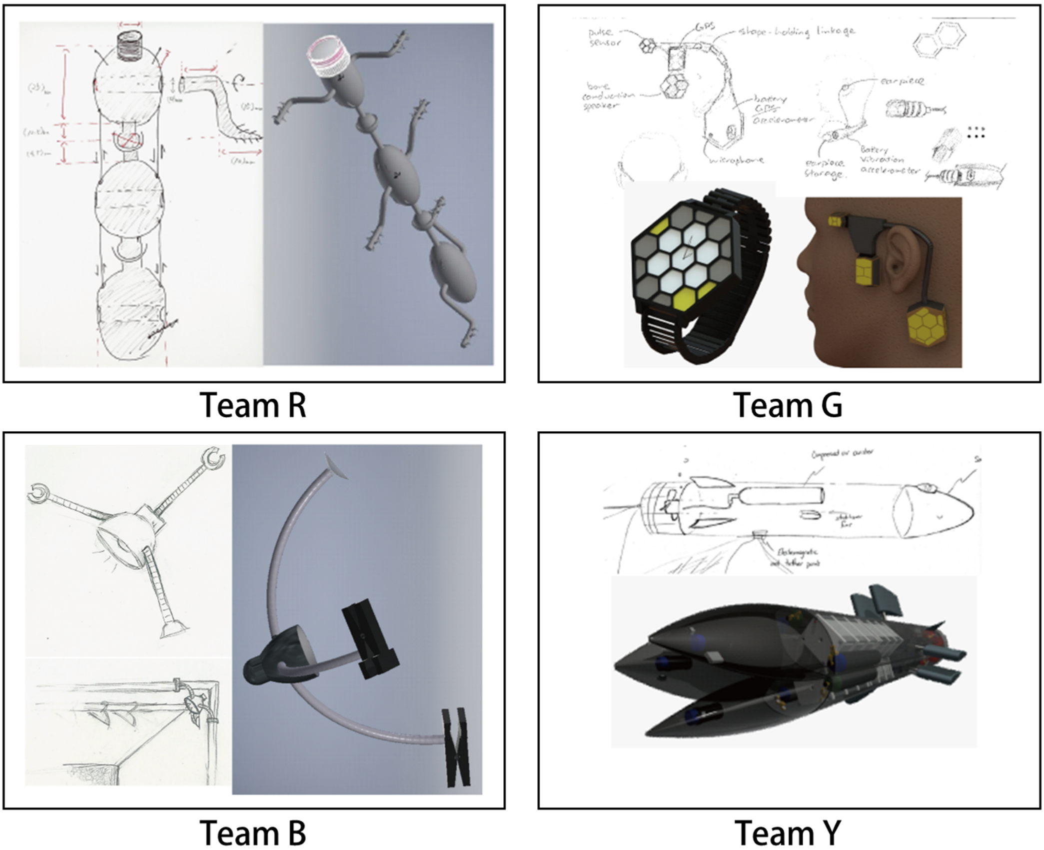


Figure 7. CAD models of design outcome.

Figure 8. Questionnaire survey results.

leader like them, specialized knowledge alone does not suffice, but a broad vision and creativity are essential.

When a breakthrough product emerges, attention is often drawn to not only what it is like and what it does, but also its 'design philosophy.' This is probably because, in addition to superb functions, a superb philosophy is expected from an excellent product design. This is also because any person who originates a breakthrough product is expected to be a sort of philosopher with deep thought, and not just an expert with superb abilities and skills. Therefore, creative persons capable of Innovation Design, who were discussed in this paper, would have to be worthy to be called a philosopher of design. As such, their regard should extend beyond products and reach society in its entirety and in the long term. These persons must have abundant knowledge, a sharp insight toward the future, and, most of all, keen sensibilities and firm convictions. As the relationship between our society and science and technology grows increasingly complex today, our society must foster excellent philosophers of design.

Notes

1. In this paper, the term 'science and technology' is used as a generic term for an understanding of the basic principles of physical phenomena and the basic knowledge required to apply such understanding.
2. In this paper, the term 'society' refers to the sphere in which products are used.
3. HondaJet has an over-the-wing engine mount design, which departs from the industry's conventional style.
4. Figure 3 shows two networks formed from our experiment, in which participants were instructed to produce a new design concept by synthesizing the two concepts of 'ship' and 'guitar.' The networks were generated by virtually connecting the two words 'ship' and 'guitar' and a set of words that the participants used to explain the design outcomes, using a concept dictionary containing hierarchically structured words.
5. Figure 4 shows the two virtual impression networks formed by virtually connecting, using a concept dictionary, all the combinations of two words selected from among the words used by participants in the experiment to express their impressions of various cups that they were shown.
6. A flash of insight in experiential intuition is deemed to occur in the process of revising preconceived notions (eliminating fixation).
7. A flash of insight in associative intuition is deemed to occur in the process of (1) or (6).

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